MODEL 401A
Lock-in Amplifier

This handbook is supplied for use with instrument serial No.........

The Company maintains a policy of constant product improvement, as the components available, and state of the art advance. This may lead to detail alterations in specification, operating procedure, or technical description. Thus handbooks should be used for the instruments with which they are supplied.

BROOKDEAL ELECTRONICS LTD, MARKET STREET, BRACKNELL,
BERKSHIRE, RG12 1JU. ENGLAND.

BRACKNELL 23931 (STD 0344)
TELEX: 847164
CABLES BROOKELEC

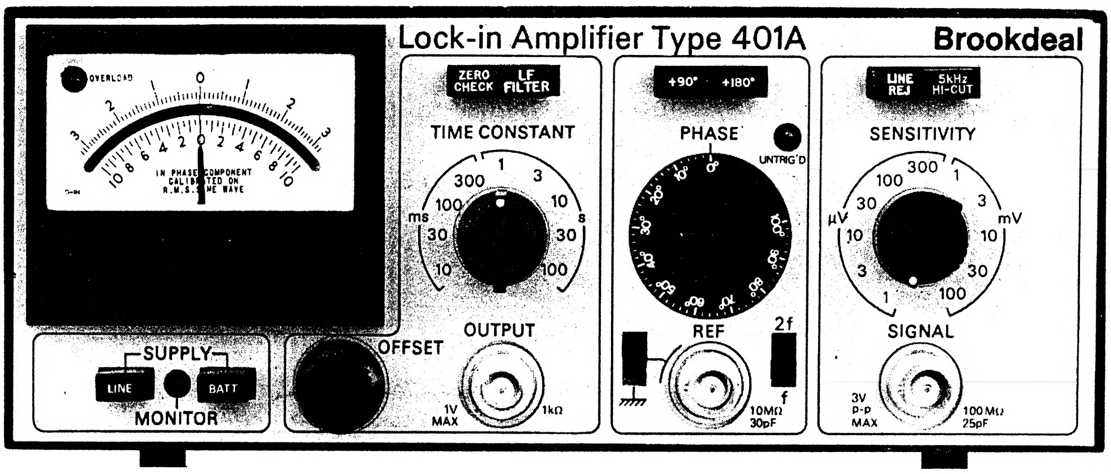
Index of contents

illustrations

1 introduction

The Brookdeal type 401A is a compact high performance lock-in amplifier capable of recovering signals up to 100dB below the noise level. Its design includes automatic circuitry which enables it to measure such signals without unnecessary setting-up procedures and also ensures continued correct operation during long period experiments.

The 401A has an input dynamic range of 100dB (10^5 voltage ratio), a low-noise input with 1µV full-scale sensitivity and wideband operation from 1Hz to 50kHz. Reference channel facilities include a calibrated phase shifter with 90° and 180° pushbuttons and special input circuitry to reduce the effects of ground loops. Alternative plug-in power packs are available for differing requirements.

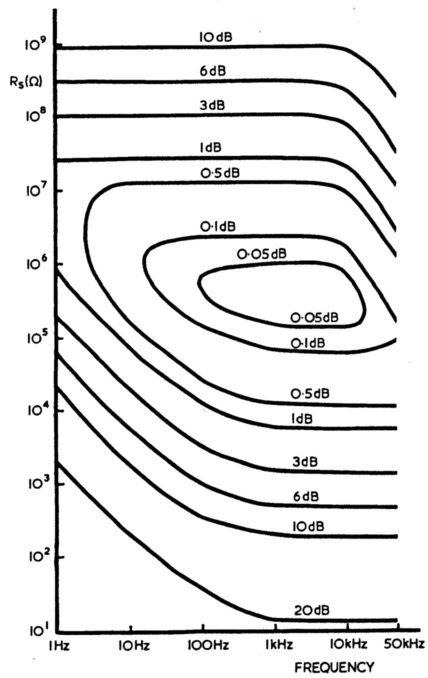


2 specification

2.1 signal channel

2.1.1	frequency range (extended mode)	+0, -3dB	1Hz to 50kHz
		±2%	10Hz to 5kHz
	(normal mode)		5Hz to 50kHz
2.1.2	impedances INPUT		100MΩ// 25pF
	SIGNAL MONITOR		1kΩ in series with 1μF
2.1.3	SENSITIVITY (for full scale)		1μV to 100mV in 1, 3, 10 steps
	accuracy (at 1kHz)		± 3%
	gain stability versus temperature		< 0.1%/°C
	gain stability for line voltage change over operating range		<0.01%
2.1.4	maximum non-coherent input voltage		1000 x full-scale or 3V p-p
	when using LINE REJECT filter		30,000 x full-scale or 3V p-p
	using the input attenuator type 4012 this may be increased to 300V p-p		
2.1.5	noise (s/c input) at frequencies > 100Hz		< 10nV/$\sqrt{Hz}$

the noise figure contours are shown below:



2.1.6 FILTERS

LINE REJECT (internally tunable)	45 to 65Hz
line rejection	> 30dB
5kHz HI-CUT roll-off	6dB/octave

2.1.7 non-linearity

intermodulation products for noise voltages 60dB above sensitivity setting and less than 3V p-p	< 0.01%

2.1.8 input dynamic range

sensitivities: 1µV	100dB
3µV	100dB
10µV	100dB
30µV	100dB
100µV	100dB
300µV	100dB
1mV	100dB
10mV	80dB } may be increased by use of attenuator type 4012
100mV	60dB }

2.2 reference channel

2.2.1 INPUT level (fundamental frequency mode)

INPUT level (fundamental frequency mode)	20mV p-p to 200V p-p
impedance (V_{IN} < 0.7V p-p)	10MΩ//30pF
(V_{IN} > 0.7V p-p)	> 10kΩ//30pF
maximum common-mode voltage	0.7V p-p
common-mode rejection	40dB

2.2.2 PHASE SHIFT

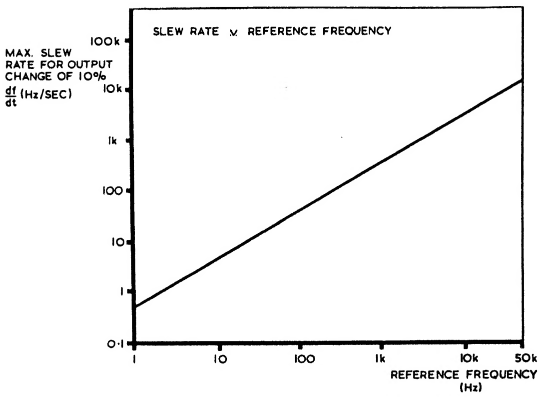
PHASE SHIFT	0° to 100° continuous variable 0° and 90° switched 0° and 180° switched

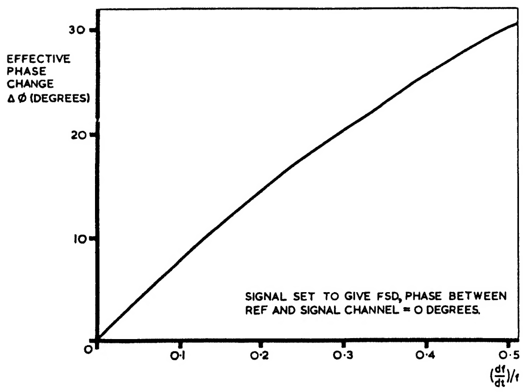
2.2.3 phase accuracy

of 90° increment	5Hz < f < 50kHz	± 1°
of 180° increment		± 0.3°
of 0° to 100° variable increment		± 2°

relative phase error between signal and reference inputs (10Hz < f < 10kHz) (squarewave or 1V p-p sinewave input)	±5°

2.2.4	frequency doubler INPUT level waveform	 200mV p-p to 200V p-p symmetrical
2.2.5	acquisition time	< (3s + 40 cycles)
2.2.6	slew rate	





2.2.7	INPUT bias (selected by internal pushbutton)	+9V applied through 10kΩ

2.3 output

2.3.1	OUTPUT level resistance	±1V max 1kΩ
2.3.2	OUTPUT stability (for signals < 50dB below the noise level) with time	 <0.1%/°C of fsd <0.03%/24 hrs
2.3.3	meter accuracy	centre zero, mirror-backed ±1% of full-scale
2.3.4	ZERO OFFSET stability	±5x full-scale <0.05% of offset value/°C
2.3.5	TIME CONSTANT accuracy roll-off	10ms to 100s in 1, 3, 10 steps ±10% 6dB/octave

2.3.6	LF FILTER 10% to 90% risetime roll-off	 ~ 5s ~ 18dB/octave
2.3.7	ZERO CHECK	front panel pushbutton
2.3.8	OVERLOAD indication	solid-state, sensed at pre-amp, main amp and psd outputs.

2.4 power packs (the 401A is used with one of the following interchangeable packs). In all cases the supply monitor indicates sufficient voltage available.

2.4.1	BATTERY PACK TYPE 4001	dry-cell, zinc-carbon batteries
	batteries supplied	3 x PP9
	life (continuous running)	> 20 hours
	control	BATT pushbutton
2.4.2	ac POWER PACK TYPE 4002	line only
	voltage ranges	100 to 130V rms 210 to 260V rms } switched
	frequency	50 - 60 Hz
	power	2W
	control	LINE pushbutton
2.4.3	RECHARGEABLE/ac POWER PACK TYPE 4003	line or NiCd batteries
	supply for line operation:	
	voltage ranges	100 to 130V rms 210 to 260V rms } switched
	frequency	50 - 60Hz
	power	2.7W
	control	LINE pushbutton
	battery operation	NiCd rechargeable cells
	continuous running capability (full charge)	> 13 hours
	recharge period (from discharge to full charge)	35 hours
	control	BATT pushbutton
	operation with LINE and BATT pushbuttons depressed	automatic charge and line to battery changeover

2.5 general

2.5.1 safe overload levels

INPUT	10V rms, ±100V pk or ±100V dc
REFERENCE INPUT	±100V pk
OUTPUT	20V rms, ±100pk or ±100V dc
SIGNAL MONITOR	±25V pk

2.5.2 dimensions

height	87mm
width	218mm
depth	380mm
weight of 401A	3kg
4001	1.75kg
4002	1kg
4003	1.7kg

2.6 alternative plug-ins available

2.6.1 ac POWER PACK AND A-D CONVERTER: TYPE 4006

2.6.2 ac POWER PACK AND OSCILLATOR: TYPE 4007

3 basic operating instructions (refer to section 5 for detailed operating instructions)

3.1 internal pushbuttons

There are two internal pushbuttons whose setting should be checked before operation: the LF pushbutton and the REFERENCE BIAS pushbutton.

The LF pushbutton should be depressed to extend the lower frequency limit from 5Hz to 1Hz. Normally use in the 5Hz position.

The REF BIAS pushbutton may be used to polarise the reference socket.

3.2 switching on

(a) BATTERY PACK TYPE 4001

Depress the BATT pushbutton on the front panel and if there is sufficient battery voltage to give correct operation the SUPPLY MONITOR will light.

(b) ac POWER PACK TYPE 4002

(i) Check that the VOLTAGE SELECTOR switch above the LINE socket is switched to the correct voltage.

(ii) Connect the instrument to the line supply and depress the LINE pushbutton. The SUPPLY MONITOR should now light showing that the instrument has sufficient voltage for correct operation.

(c) RECHARGEABLE/ac POWER PACK TYPE 4003

(i) Operation in LINE mode

Check that the VOLTAGE SELECTOR switch above the LINE socket is switched to the correct voltage. Connect the instrument to the line supply and depress the LINE pushbutton. The SUPPLY MONITOR should now light showing that the instrument has sufficient voltage for correct operation.

(ii) Operation in BATT mode

The instrument may be operated from the internal rechargeable batteries by depressing the BATT pushbutton. The SUPPLY MONITOR will light if the batteries are sufficiently charged.

(iii) Operation in LINE/BATT mode

When the instrument is connected to line and both the

(iii) Operation in LINE/BATT mode

When the instrument is connected to line and both the LINE and BATT pushbuttons are depressed:

The line will charge the internal batteries.

In the event of line failure the instrument will automatically change to battery power.

In the event of line power being restored during the running time of the internal batteries the instrument will automatically revert to line power.

(d) ac POWER PACK AND A-D CONVERTER: TYPE 4006
ac POWER PACK AND OSCILLATOR: TYPE 4007

Operation of the power packs in these two plug-ins is the same as for the ac POWER PACK TYPE 4002 given in (b) above.

3.3 setting the controls

(a) Connect the REFERENCE voltage and the SIGNAL voltage. (Note that the meter is clamped near zero for approximately 10 seconds after connecting the reference voltage).

(b) Check that the low side of the reference is grounded at one point in the measurement system.

(c) Check that the reference UNTRIGGERED light is extinguished.

(d) Select a suitable TIME CONSTANT (for setting up, typically 1 second).

(e) Select the f position of the frequency doubler switch for fundamental frequency measurements. Select the 2f position for 2nd harmonic measurements.

(f) Press the LF FILTER pushbutton if the frequency of the signal of interest is <10Hz. (This is not advisable in certain applications e.g. servo systems).

(g) Press the LINE REJECT button if line interference causes overload.

(h) Press the 5kHz HI-CUT button to reduce the effect of high frequency noise when operating at frequencies below 3kHz.

(i) Press the ZERO CHECK button and adjust the OFFSET control for zero, keeping the ZERO CHECK button pressed. Release the ZERO

CHECK button. Note that the TIME CONSTANT will be as selected when using the ZERO CHECK.

(j) Increase the SENSITIVITY to obtain an on-scale indication on the meter.

(k) Use the variable PHASE control, and if necessary the 90° pushbutton to null the output.

(l) Use the 90° pushbutton to change the phase. This maximises the output.

(m) Select the required output polarity by means of the 180° pushbutton.

(n) Set SENSITIVITY to anticipated maximum signal level.

(o) If there is low frequency chop or beats from the output press the LF FILTER button (unless already carried out as in (f) above).

(p) If the OVERLOAD indicator on the meter panel lights refer to section 5.7.

(q) Readjust TIME CONSTANT and OFFSET controls as necessary and read signal level on the meter.

3.4 output specifications

(a) The OUTPUT connector provides a full-scale output of ±1V dc from a resistance of 1kΩ.

(b) The SIGNAL MONITOR socket (rear panel) enables the input to the phase-sensitive detector (demodulator) to be monitored.

4 principles of operation

4.1 introduction

A lock-in amplifier is an instrument which uses the principle of phase-sensitive detection to measure the mean amplitude of an ac signal buried in noise. It usually consists of a signal amplifier, a phase-sensitive detector (psd) and a phase shifter.

It is used in applications where the wanted signal results from the application of an ac stimulus to a system under test. See figure 1.

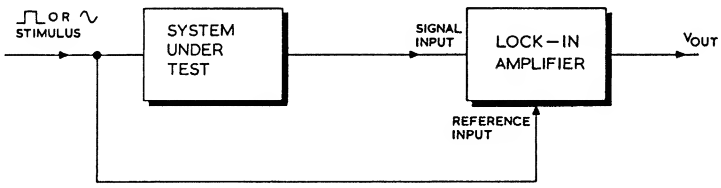


fig 1

In order for the lock-in to operate, it requires a reference voltage which is coherent with the signal of interest. Therefore a voltage derived from the stimulus (which may be mechanical, optical, magnetic etc.) is applied to the reference input. A variable phase shifter is included in the reference channel so that the reference voltage applied to the psd itself is in-phase with the required component of the signal. The output comprises a dc voltage proportional to the required component of the signal and also ac components due to noise. The ac components due to noise are filtered with a low-pass filter of variable time constant.

The basic schematic of the lock-in amplifier is shown in figure 2. It includes a signal channel amplifier, reference channel circuits (including phase shifter and squarewave generator), a psd and an output filter.

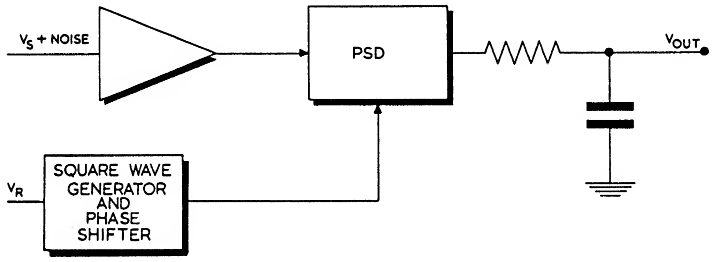


fig 2

4.2 principles of signal recovery by phase-sensitive detection

Most psd's work on the principle of the synchronous switch (figure 3). The signal is periodically switched into the load resistor, the frequency and phase of the switching operation being determined by the reference voltage.

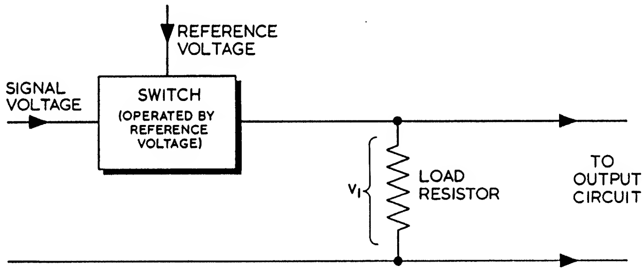


fig 3

It is clear that if the signal and the reference voltages have the same frequency and phase, the voltage appearing across the load resistor will have the form shown in figure 4. That is, the switch will act as a half-wave rectifier for signals of the same frequency and phase as the reference.

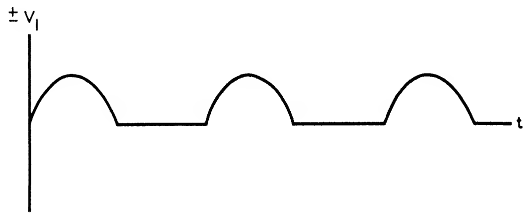


fig 4

If the signal is in quadrature with the reference, the corresponding waveform will be that shown in figure 5, and rectification will not occur. Intermediate phase angles give a dc output proportional to the in-phase component.

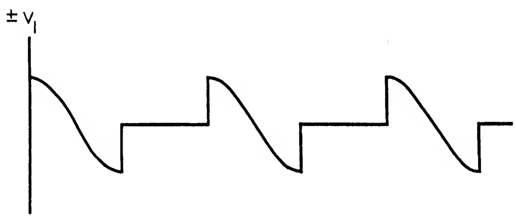


fig 5

This action may be summarised as follows:

> Let the reference voltage be $V_r \sin\omega t$. Then if the signal voltage is $V_s \sin(\omega t + \alpha)$ a dc voltage will appear across the load resistor proportional to $V_s \cos\alpha$.

Noise voltages in the signal input, which are not coherent with the reference signal, will give an ac voltage across the resistor at the difference frequency. Thus the response of the system to noise will depend on the time constant T_0 of the dc measuring circuit and the psd acts as a selective rectifier of bandwidth $1/T_0$ radians/sec. Thus by use of the appropriate time constant the desired bandwidth for the entire system may be obtained.

It should be noticed that the psd also responds, with reduced sensitivity, to noise bands centred on frequencies which correspond to odd harmonics of the reference frequency: with a flat noise spectrum this effect reduces the effective signal/noise ratio by 1dB. Although this extra noise is usually negligible, it can be eliminated by limiting the high-frequency response of the signal amplifier.

The psd shown in figure 3 is unbalanced. A better performance can be obtained by using a balanced switching circuit with a two-way switch connected to two load resistors as shown in figure 6.

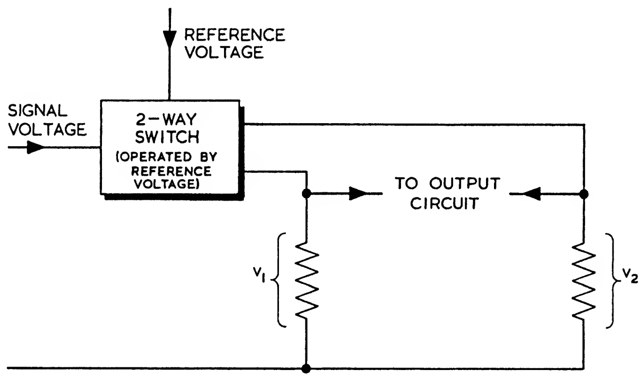


fig 6

The voltages across the two load resistors obtained with an in-phase signal are shown in figure 7. It is seen that the balanced psd gives full-wave rectification, rather than half-wave rectification, into the dc measuring device: this corresponds to an improvement of 3dB in signal/noise ratio if the noise spectrum is "white" but it may be greater or less than this according to the form of the noise spectrum.

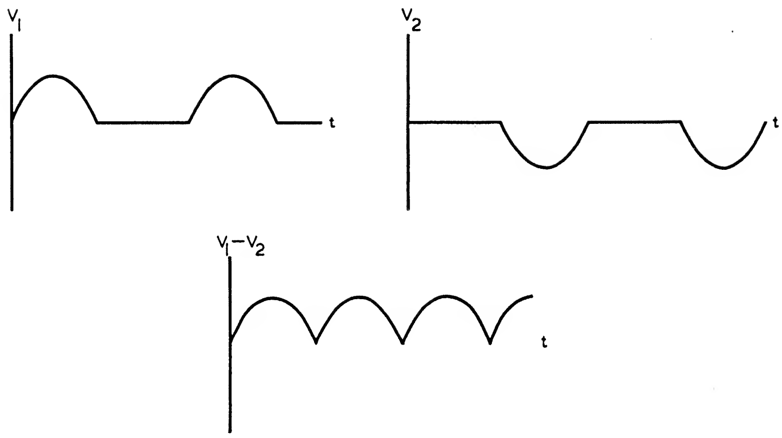


fig 7

Mathematically, the operation performed by the psd corresponds to multiplying the signal input voltage by a square wave, that is by function $F_1(t)$ where

$$F_1(t) = \sin\omega t + \tfrac{1}{3}\sin 3\omega t \text{ ------}$$

so that if the signal voltage is $V_S F_2$ (t) the output is

$$(V_1 - V_2) = V_s \overline{F_1 F_2}$$

where the averaging time is T_o.

Thus the psd performs a Fourier analysis of $F_2(t)$ and extracts the component corresponding to $\sin\omega t$ (and its odd harmonics).

4.3 lock-in characteristics

As explained above, a lock-in amplifier extracts a signal from noise by multiplying the signal input voltage with the reference and then filtering the product with a low-pass filter of time constant T_o. The overall filter characteristic given by the system (if the filter is first order) is that of a second order bandpass filter centred on the reference frequency whose noise equivalent bandwidth is:

$$[\Delta f]_{out} = \frac{1}{4T_o}$$

The time constant T_o of the 401A is variable from 10ms to 100s and therefore the noise equivalent bandwidth can be varied between 25Hz and 0.0025Hz.

(a) signal/noise improvement with white noise

For a given white noise source the noise voltage is proportional to the square root of the noise bandwidth. Therefore the improvement in voltage signal/noise ratio obtained with a lock-in amplifier is given by taking the square root of the ratio of the noise bandwidth of the input signal and the noise bandwidth of the lock-in filter.

$$\frac{\text{voltage signal/noise ratio at output}}{\text{voltage signal/noise ratio at input}} = \frac{\sqrt{[\Delta f]_{in}}}{\sqrt{[\Delta f]_{out}}}$$

for example, the improvement in voltage signal/noise ratio for $[\Delta f]_{in}$ = 100kHz and T_o = 10s is:

$$\frac{\sqrt{[\Delta f]_{in}}}{\sqrt{[\Delta f]_{out}}} = \frac{\sqrt{[\Delta f]_{in}}}{\sqrt{\frac{1}{4T_o}}} = \frac{\sqrt{10^5}}{\sqrt{\frac{1}{(4 \times 10)}}} = \sqrt{(4 \times 10^6)} = 66\text{dB}$$

(b) signal/noise improvement with narrow-band noise

The lock-in can give enormous improvement in signal/noise ratio when dealing with narrow-band noise. (Under the heading "narrow-band noise" we may include such interfering signals as line pick-up etc.) The usual reason for this lies in the high-order filtering effect of the readout equipment normally employed (moving-coil meters, chart recorders etc). In the case of the 401A this may also be achieved by the multi-stage LF FILTER so that improvements in signal-noise ratio as great as 100dB may be obtained. (See 4.4.3).

(c) input dynamic range

It can be seen from the above paragraphs that the lock-in amplifier has a fundamental capability of recovering signals several orders of magnitude below the input noise level but in order to use this ability to the full it requires a correspondingly large input dynamic range. This is defined as:

> the ratio of the maximum non-coherent input voltage allowed for a given sensitivity setting to the "minimum detectable" * in-phase input voltage at the same sensitivity setting

Thus the input dynamic range is the most important factor in evaluating the ability of a lock-in to recover signals from noise because unless it is greater than the input noise/signal ratio the lock-in will give degraded results.

*The "minimum detectable" input voltage is conventionally taken as the signal level which gives rise to an output equal to the maximum dc errors. With the 401A it is often possible to resolve far below this level under constant noise conditions.

(d) dynamic reserve

A design factor which is also of importance when handling very small signal/noise ratios is dynamic reserve. This is defined as:

> the ratio of the maximum non-coherent input voltage allowed for a given sensitivity setting to the in-phase input voltage required to give full-scale output at the same sensitivity setting

Neither input dynamic range nor dynamic reserve will determine whether it is physically possible to recover a particular signal under a given set of noise conditions: that is governed by the principles given in sections (a) and (b) above. However the figure for input dynamic range does establish whether the instrument is basically capable of handling a given signal/noise ratio. The figure of dynamic reserve shows whether or not the instrument will be able to give a full-scale output with a given set of conditions.

Input dynamic range and dynamic reserve are functions of the circuit design and are related to temperature drift in the phase-sensitive detector/dc amplifier, out-of-phase rejection † in the phase-sensitive detector and dc gain. The relation between maximum noise input, full-scale signal input, zero errors, input dynamic range, dynamic reserve and output dynamic range is shown in figure 8.

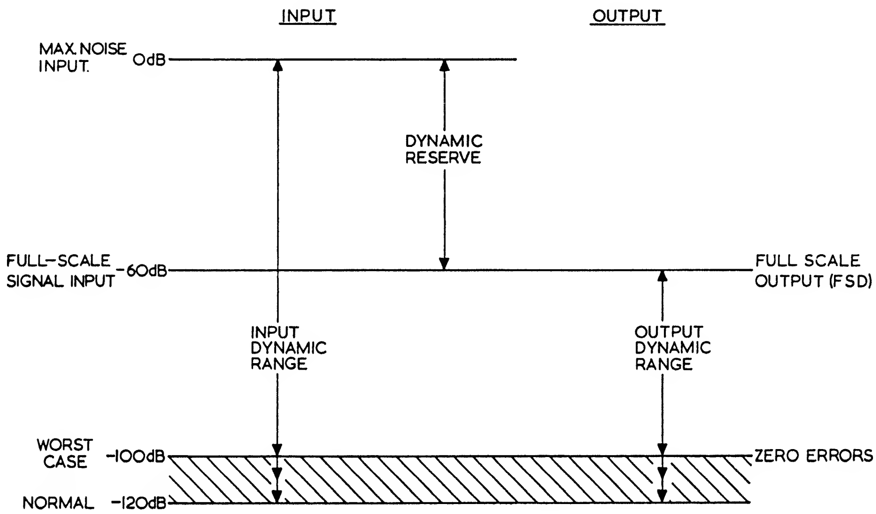


fig 8

† Any practical design of phase-sensitive detector exhibits a certain amount of even-order non-linearity which has the effect of generating a dc output from noise input voltages. In this it is unlike the ideal phase-sensitive detector which gives a dc output only for in-phase input signals, outputs due to noise always being ac and therefore reducible by the low pass output filter. The term "out-of-phase rejection" is used to describe this departure from the ideal and may be defined as:

> the dc error referred to the input caused by the maximum allowable non-coherent input voltage

The 401A obtains its large input dynamic range by incorporating a new design of phase-sensitive detector. This psd has zero drift referred to maximum input level < 0.0001%/°C, and out-of-phase rejection referred to maximum input level < 0.0005%. Because of these ultra-low zero errors it has been possible to incorporate 60dB of effective dc gain (and thus obtain the dynamic reserve of 60dB) and still retain a high degree of output stability.

4.4 system design of the 401A

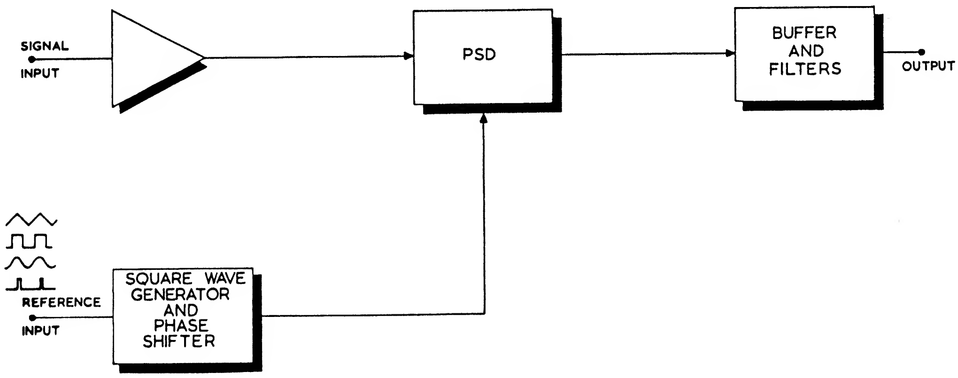


fig 9

The basic form of the 401A is shown in figure 9. It consists of a signal channel with variable gain and filtering, a reference channel with phase shifting and square wave generation circuits, and the psd with its dc output circuits.

4.4.1 signal channel

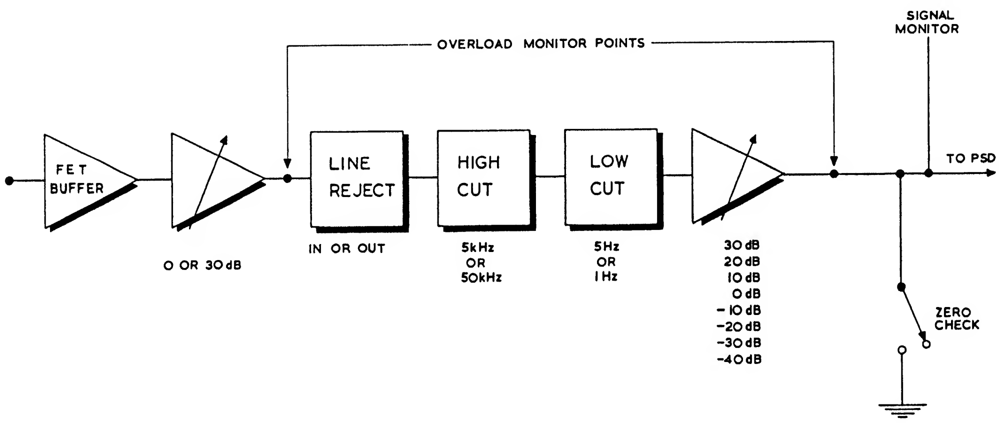


fig 10

The input amplifier comprises a low noise fet input buffer and a low noise variable gain amplifier. Following the input amplifier is a series of filters which are specially chosen to eliminate the effects of three different kinds of interference without introducing operational difficulties. These are:

LINE REJECT

This is designed to give an extra 30dB rejection of line interference and should be used when this interference is considerably greater than the signal - as much as, say, 60dB or more. Its typical amplitude and phase responses when adjusted to 50Hz (it may be adjusted from 45-65Hz) are shown in figure 11. Note that its characteristic is sufficiently broad to allow for normal variations in the line frequency.

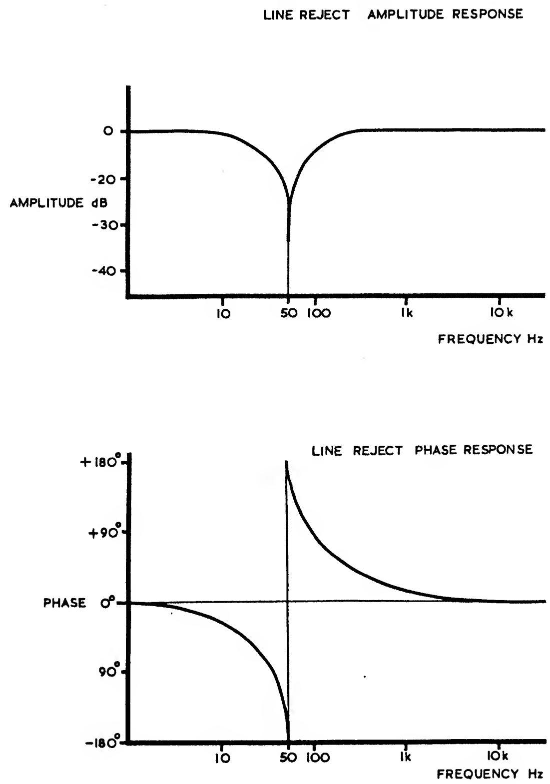


fig 11

HI-CUT

The upper frequency limit (-3dB point) of the 401A signal channel is 50kHz. The HI-CUT filter may be used to reduce the response to 5kHz for operation at frequencies < 3kHz.

low cut (internal button labelled LF)

The low cut filter is normally set to give a lower 3dB point at 5Hz. However for low frequency operation (< 10Hz) it can be set to 1Hz.

NOTE: In the majority of applications the extra noise rejection given by these filters will not be observable. However the 401A is designed to operate under extreme noise conditions and it is for these cases that the filters are provided.

The filters are followed by an amplifier block which gives gains in 10dB steps from 30dB down to -40dB. The output of this block which goes into the psd signal circuit may be monitored. It may also be grounded by the ZERO CHECK switch.

4.4.2 reference channel

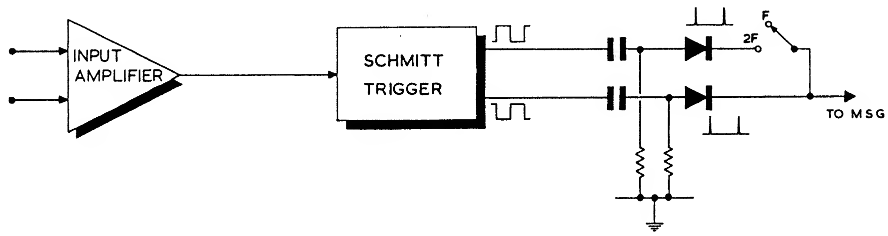


fig 12

The 401A reference channel has the following characteristics.

(a) It is a symmetrical square wave generator which is triggered by the reference input; the trigger point on the waveform being at the mean level on the positive going edge.

(b) Its output frequency may be doubled also without frequency selection etc.

(c) The trigger input is differential in order to minimise ground loops in many applications.

(d) The phase of its output with respect to input may be shifted by a calibrated amount without the need for frequency range selection or tuning.

The input stage of the reference channel is a differential amplifier connected to a Schmitt trigger which is arranged to trigger from the positive going edge near to the mean level of the input waveform. The two antiphase outputs of the Schmitt are differentiated and diode connected to the following circuit.

Under normal operation only one output is used. For frequency doubling purposes both antiphase outputs of the Schmitt are used to drive the following circuit, the triggering of the input stage being arranged such that provided the input waveform contains no even order harmonics the two pulse trains combine to give evenly spaced pulses at twice the input frequency.

The reduction of ground loop effects by a differential reference input circuit can be seen by comparing figures 13(a) and 13(b). In 13(a) is shown a lock-in amplifier (with single-ended inputs) connected to a system under test in which there is a direct connection between the input and output of the system.

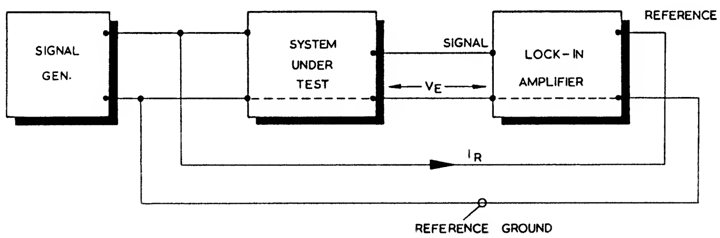


fig 13(a)

It is evident that the reference current i_R taken by the lock-in amplifier can return both down the reference ground line and, because of the continuous ground connection within the lock-in amplifier, by the signal ground line. The latter creates an ac voltage V_E which is indistinguishable from the signal voltage.

In 13(b) the reference ground is connected to one side of the differential reference input (as used in the 401A) and thus there is no way for the return reference current to go via the signal ground.

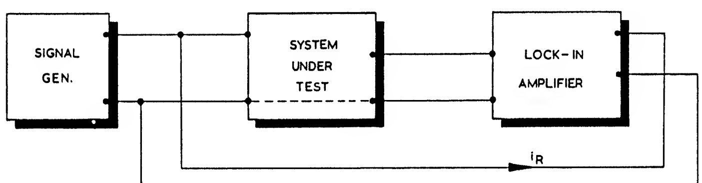


fig 13(b)

In order to describe the principles by which the square wave generation and phase shifting are obtained it is necessary to describe the basic control system used which is called a 'mark space generator' (msg). This is a circuit which, when stimulated by repetitive pulses, generates a "square wave" of the same repetition rate. The mark-space ratio of this square wave is independent of the repetition rate and is only determined by a programme voltage (V_p). The operation is summarised in figure 14.

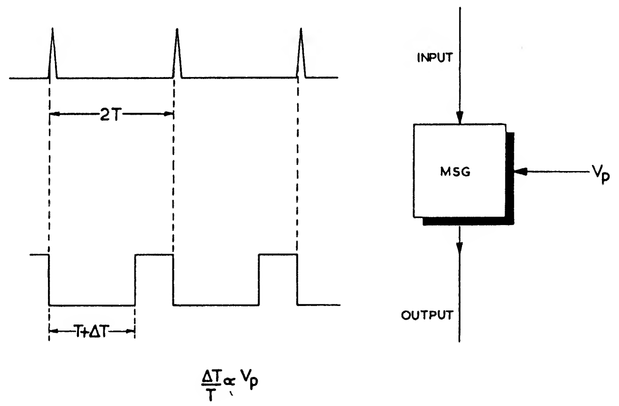


fig 14

The msg provides the two basic functions of the reference channel:-

(a) generation of symmetrical square waves. In this case the msg is supplied with repetitive pulses and V_p is set to zero volts. Thus $\Delta T = 0$ and the output of the msg is a symmetrical square wave.

(b) generation of calibrated phase shift. The object in this case is to produce a pulse train shifted by a known phase from an input pulse train, and the method is shown in figure 15.

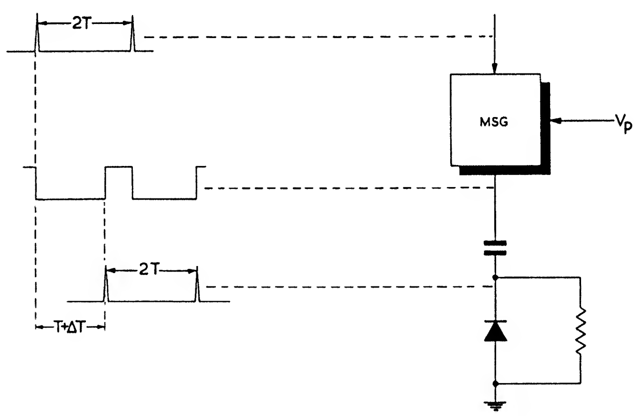


fig 15

The msg is connected to a diode-resistor network so that the output consists of pulses generated by the positive-going edge of the msg output. These are shifted with respect to the input by a time $T + \Delta T$, that is by 180° $(1 + \Delta T/T)$ in phase. Since $\Delta T/T \propto V_p$ then the phase shift produced is $180^{\circ} + kV_p{}^{\circ}$, where k is a constant. In the phase shift mode the msg is used either as a variable phase control by varying V_p or as a fixed 90° phase shift block by applying the appropriate fixed value of V_p.

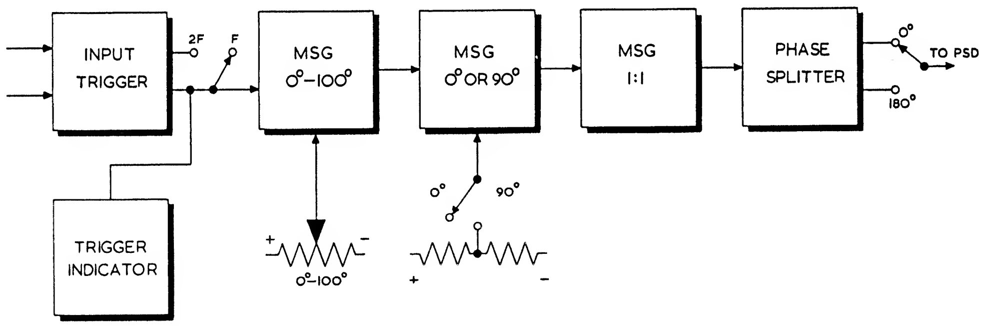


fig 16

After the input trigger there are two msg's (figure 16), one controlled by a variable dc voltage giving 0° - 100°, the other controlled by a switched dc voltage giving 90° increment. Following these is the msg which provides the switching voltage for the psd, which has two antiphase outputs providing 0° and 180° phase switching.

4.4.3 the psd and output filter circuits

The psd in the 401A is specially designed to operate correctly under severe noise conditions so as to minimise the filter requirement of the signal channel and thus give precise measurement and easier operation. Its principle of operation is shown in figure 17.

It comprises a fully balanced, current-switching mixer which has 60dB inherent gain so that, whilst being able to tolerate noise voltages at its input up to 3V p-p, it gives full output (±1V dc) for a coherent input voltage of approximately 3mV p-p. The ratio of maximum noise voltage to the coherent voltage required to give full scale output is called dynamic reserve, see section 4.3 (d). In the 401A it is, under most conditions, 60dB (3V ÷ 3mV).

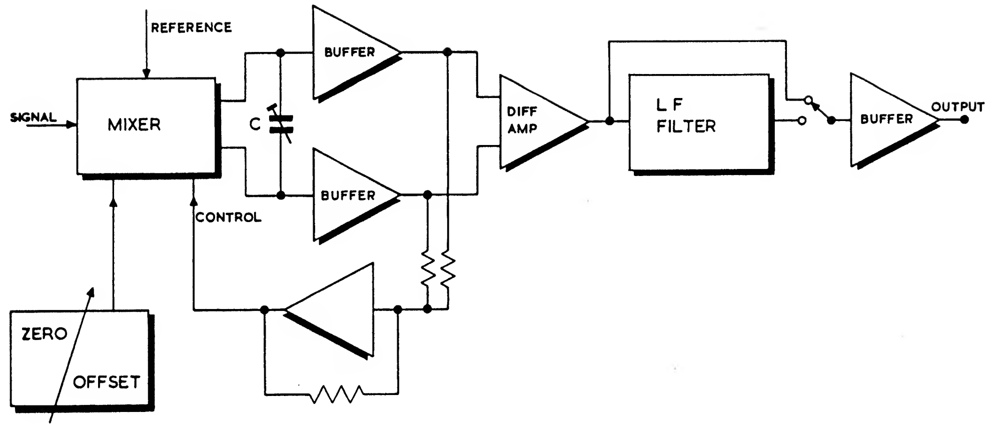


fig 17

The antiphase outputs of the mixer are buffered and applied to a summing amplifier which feeds back to a control input of the mixer. This stabilises the mean level of the outputs so that despite the high inherent gain, excellent output stability is obtained.

The buffered outputs are also applied to a differential amplifier to provide a single-ended output. This goes into a switched multi-stage filter (LF FILTER) and then via a buffer to the output.

The bandpass characteristic of the lock-in is determined by the output filters. In the 401A the main output filtering is determined by the TIME CONSTANT (T_0) of the switched capacitor C and the output impedance of the mixer. The characteristic given by a TIME CONSTANT equal to 3s is shown in figure 18 together with that of the LF FILTER.

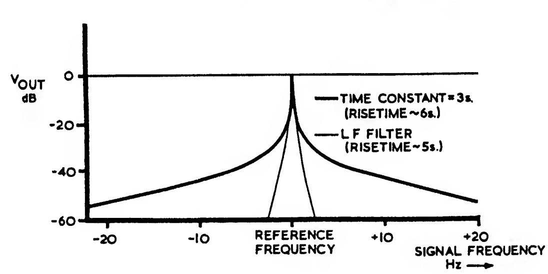


fig 18

The difference in characteristic is important because even though the risetime of each filter is similar their applications are quite different. For reducing random noise the TIME CONSTANT is normally used since its magnitude can be varied to suit the noise reduction required. However if the noise is a discrete frequency (only 2Hz from the reference for example) the LF FILTER will give > 50dB rejection compared with 30dB for the 3s TIME CONSTANT. The TIME CONSTANT required to give the same rejection in this example would be 30s (risetime ~ 60s). Thus the LF FILTER is often used to remove low frequency beats at the output.

The zero offset current is applied to the output terminals of the mixer circuit. A coherent signal five times greater than that required to give full scale output can be supplied to the input and the resulting dc output suppressed without mixer overload occurring.

4.4.4 overload indicator

In the 401A overload is monitored at three points: before the signal channel filters, at the input to the psd and at the output of the psd. Under normal operating conditions overload in the signal channel due to noise alone rarely occurs owing to the ability of the 401A to give full scale even in the presence of 60dB noise, provided that the TIME CONSTANT is set to a sufficiently large value to give output fluctuations which are less than the signal.

Thus if there is overload indication while the output meter remains on-scale, the overload may usually be prevented by increasing the TIME CONSTANT rather than decreasing the SENSITIVITY.

5 facilities and detailed operating instructions

5.1 power packs

facilities

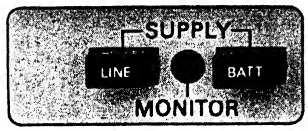
The 401A is designed for use with one of the following interchangeable plug-in power pack options:

The 4001 BATTERY POWER PACK is a drycell battery power pack using 3 zinc-carbon batteries of IEC type 6F100 which give more than 20 hrs continuous running. Alternative batteries which may be used are:

Country	type
Europe	Berec PP9
Australia	Eveready 276
Denmark	Hellesens 480 and 780
Finland	Airam LP5M9
France	Leclanche 6NX
France	Ceipel RO617
Germany	Varta Pertrix 439
Germany	Daimon 339
Germany	Baum Garten 495
Italy	Sole 592
Italy	Superpila 995
Japan	Novel N572/306
Norway	Anker/Pertrix 439
Singapore	Eveready 276
South Africa	Eveready PM9
Spain	Tudor PT673
Sweden	Tudor 9T1
Switzerland	Leclanche 821
UK	Eveready PP9
UK	Vidor VT9
UK	Exide DT9
USA	Eveready 276
USA	Mallory M-1603

The 4002 ac POWER PACK operates from ac supplies of 100V to 130V or 210V to 260V, 50/60Hz. The LINE socket is situated on the rear panel of the 4002.

operating instructions

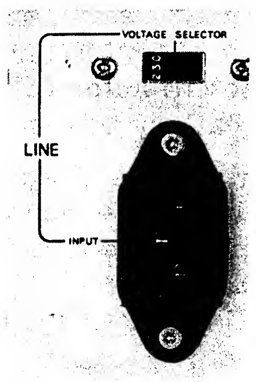


Depress the BATT pushbutton on the front panel and if there is sufficient battery voltage to give correct operation the SUPPLY MONITOR will light. To change the batteries undo the two knurled screws at the back and remove the complete battery pack. The batteries may then be removed by unscrewing the retaining screw on the battery clip which can be lifted off.

The line cord must be connected as follows:-

European colour coding

connect to live	brown
connect to neutral	blue
connect to ground	green/yellow



The 4003 RECHARGEABLE/ac POWER PACK enables the 401A to be operated from ac line supplies of 100V to 130V or 210V to 260V, 50/60Hz, or from internal rechargeable nickel cadmium cells. The LINE socket is situated on the rear panel of the 4003.

CSA colour coding

connect to live	black
connect to neutral	white
connect to ground	green

Check whether the line supply is 115V, or 230V, and that the VOLTAGE SELECTOR switch above the LINE socket is switched to the correct voltage.

Connect the instrument to the line supply and depress the LINE push-button. The SUPPLY MONITOR should now light showing that the instrument has sufficient voltage for correct operation.

The line cord must be connected as for the 4002.

(i) operation in LINE mode

Check whether the line supply is 115V or 230V and that the VOLTAGE SELECTOR switch above the LINE socket is switched to the correct voltage. Connect the instrument to the line supply and depress the LINE pushbutton. The SUPPLY MONITOR should now light showing that the instrument has sufficient voltage for correct operation.

(ii) operation in BATT mode

The instrument may be operated remote from line sources using the internal rechargeable batteries by depressing the BATT pushbutton. The SUPPLY MONITOR will light if the batteries are sufficiently charged.

(iii) operation in LINE/BATT mode

When the instrument is connected to line and both the LINE and BATT

pushbuttons are depressed:

The line will charge the internal batteries.

In the event of line failure the instrument will automatically change to battery power.

In the event of line power being restored during the running time of the internal batteries the instrument will automatically revert to line power and charge the batteries.

The 4006 ac POWER PACK AND A-D CONVERTER and 4007 ac POWER PACK AND OSCILLATOR are alternative plug-ins which operate from ac supplies of 100V to 130V or 210V to 260V, 50/60Hz.

Connection of the line cord and operation of the power pack is as for the 4002.

More detailed operating instructions for the 4006 and 4007 are given in the respective manuals for these plug-ins.

5.2 Fuses

The single line FUSE is found on the rear panel of the power packs type 4002 and 4003. The correct fuse specifications are:-

Line Voltage	fuse 20 x 5mm slow-blow
115V	100mA
230V	100mA

The dc supply has a 100mA slow-blow 20 x 5mm fuse which is found inside the instrument on the rear panel of the 401A.

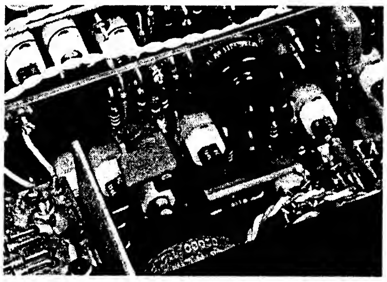
5.3 Signal channel

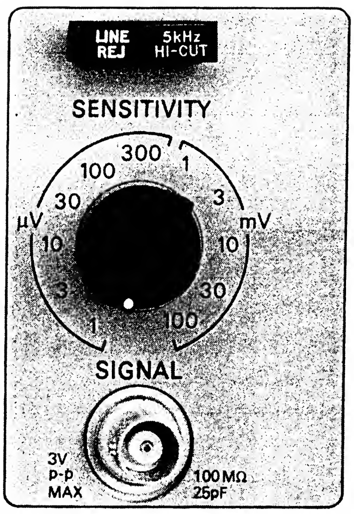
The signal channel operates over a frequency range 1Hz to 50kHz and will accept in-phase signals up to 100mV rms and noise voltages up to 3V p-p. This frequency range may be altered by an internally operated low-cut filter labelled LF, a high-cut filter labelled 5kHz HI-CUT and a line frequency notch filter labelled LINE REJ. The centre frequency of the LINE REJ filter is internally adjustable from 45 to 65Hz. This internal control is

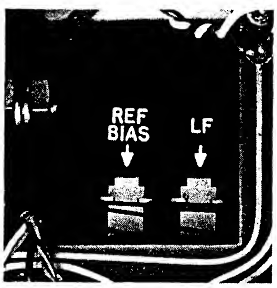
For best performance make certain that the signal source is properly screened and connected via coaxial cable to the SIGNAL input socket. The 401A input circuitry is suitable for most signal sources but under certain circumstances special matching precautions may need to be taken:-

facilities

found near the top edge of the plug-in circuit board nearest the front of the instrument.







operating instructions

(i) If the input signal or noise exceeds the maximum permitted input level the miniature plug-on input attenuator type 4012 should be used to reduce it to an acceptable level (since all input attenuators degrade the noise figure the 4012 should only be used when necessary).

(ii) If the experiment is Johnson noise limited and the source resistance is less than 1kΩ a signal/noise improvement may be obtained by using a suitable preamplifier such as the type 431.

(iii) If a differential input is required the high |Z| amplifier type 432 should be used.

Only depress the internal button marked 'LF' if the frequency of operation is below 10Hz. Similarly if the operating frequency is less than 3kHz the 5kHz HI-CUT pushbutton may also be depressed.

The LINE REJECT facility should be used when line interference is so great that full-scale output from the 401A is not obtainable without overload taking place. The presence of excessive line interference may be verified by observing the output from the SIGNAL MONITOR socket (on the rear panel) with an oscilloscope. Note that the use of the LINE REJ filter may have an effect at the signal frequency. See section 4.4.1. If this is the case the phase and sensitivity may need readjustment.

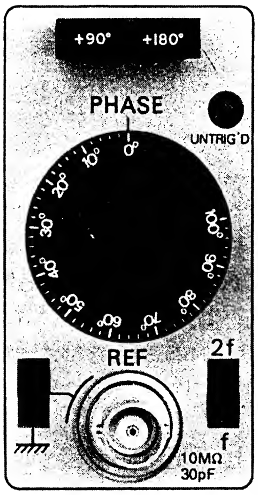
5.4 reference channel (fundamental frequency measurements)

The reference INPUT accepts frequencies between 1Hz and 50kHz: the waveform may be of any shape provided it crosses its mean level

Plug in the reference voltage making sure that the trigger indicator goes out. If there is any doubt as to the frequency at which the reference

once in each direction per cycle. The minimum time between successive crossings must be greater than 5µs. The input level must lie between 20mV p-p and 200Vp-p, the absence of triggering being indicated by a front panel led.

A dc bias may be applied to the reference socket by means of an internal pushbutton situated next to the LF button. See section 5.3



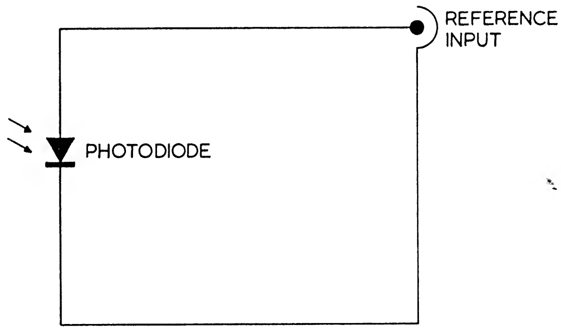
The reference input is differential and thus reduces reference ground currents of the type described in section 4.4.2 to a negligible level provided the reference input voltage does not exceed 0.7Vp-p. Voltages in excess of this value will cause small ground currents to flow which may give coherent error voltages at the input of up to 10nV.

The differential input can tolerate common-mode voltages of up to 0.7Vp-p.

Using the 90° and 180° pushbuttons and the 0-100° variable control calibrated phase adjustments may be made.

is triggered the 401A output, with the TIME CONSTANT at 10ms, should be monitored on an oscilloscope when a triangular waveform at the reference frequency will be observed.

If the reference source is a photodiode (or phototransistor), a polarising voltage may be applied to the reference socket by depressing the internal REF BIAS pushbutton. The photo-diode is connected as shown below.



To avoid common-mode voltages in excess of 0.7Vp-p occurring at the reference input it is essential that the reference low is grounded at one point in the measurement system.

Having plugged in SIGNAL and REFERENCE voltages the phase may be adjusted making certain first, using the ZERO CHECK and

OFFSET controls that the output is zero. Release the ZERO CHECK and, by using the variable PHASE control and if necessary the 90° pushbutton, set the output to zero. (The sensitivity may need to be increased in order to adjust the phase accurately). Then change the phase by 90° and the output will be maximised. Select the required output polarity by means of the 180° pushbutton.

5.5 reference channel
(2nd harmonic measurements)

A front panel switch labelled 2f may be used to cause the reference channel to operate at twice the frequency of the reference input. In this mode all facilities are the same as in the fundamental mode except that the reference input must be greater than 200mV p-p and its waveform should be symmetrical.

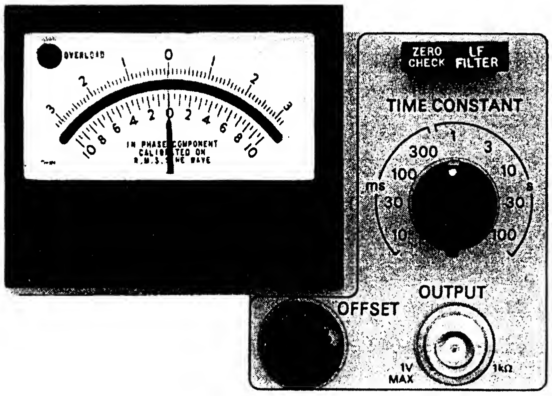
Apply a reference voltage which should normally be a low distortion sinewave and select the 2f position on the front panel switch. The phase is adjusted as in the above section.

5.6 output

The output section contains four controls: the OFFSET control which provides up to five times full-scale zero suppression, the ZERO CHECK pushbutton which zeros the input to the psd and allows setting of the OFFSET, the single-section switched TIME CONSTANT and the three section (~18dB/octave) LF FILTER. The use of these last two controls is described in section 4.4.3. The output is ±1V dc from 1kΩ and is displayed on the centre zero meter.

Set the TIME CONSTANT to the lowest value which gives acceptable noise fluctuations at the output. The LF FILTER may be selected to reduce chop or difference frequencies at the output. It should also be used when the frequency of operation is < 10Hz. (This is not advisable in certain applications eg servo systems)

For measurement of small changes in signal level, the OFFSET control may be used to suppress output for signals up to five times full-scale.



NOTE: When the instrument is switched on, but no REFERENCE input is applied the meter is clamped to give a reading near to zero. When a reference is applied there is a delay of approximately 10 seconds before the instrument is operative. Alternatively, if the instrument is switched on with a reference already present at the REFERENCE input, the clamp operates for approximately 20 seconds. The clamps are designed to remove output fluctuations which would otherwise occur as the internal circuitry settles to its normal operating conditions.

The OUTPUT may be connected directly to chart recorders or digital voltmeters. If a digital output is required the plug-in type 4006 ac POWER PACK AND A-D CONVERTER should be used. In the case of chart recorders of fixed high sensitivity (eg 10mV full-scale) the output of the 401A should be reduced with a shunt resistor.

The sensitivity selector scale uses the 1, 3 gain sequence convention. Actual changes in gain are in 10dB steps. Hence, when a signal is measured at two sensitivity settings and the output is observed on a DVM, XY recorder, etc, then the ratio of the two measured values should be 3.16:1. If the output is observed on the meter then the values are as indicated on the meter scales.

5.7 overload indicator

A led indicator is situated in the meter and indicates overload at three points:

prefilter, psd input and psd output.

It is important to realise that the overload indicator will light when the meter is off-scale.

Therefore it is not possible to remove overload unless the meter is first brought on to scale. This

may be due to incorrect setting of the OFFSET control or too much SENSITIVITY.

Because of the large dynamic reserve of the 401A, overload indication is not usually due to pre-filter or psd input overload. It is usually caused by excessive ac components at the psd output. Therefore first increase the TIME CONSTANT. If this does not remove the overload verify the nature of the noise by observing the signal channel at the SIGNAL MONITOR socket with an oscilloscope. In most cases the overload will be due to line frequency interference and should be removed by using the LINE REJ filter. If this fails to remove the overload the SENSITIVITY should be decreased and if, in extreme circumstances the overload is caused by input voltages in excess of 3V p-p they should be reduced by the 4012 input attenuator accessory.

NOTE: After use of the internal controls make certain that the top lid is replaced with the foam rubber strips towards the front of the instrument.

6 applications of the 401A

The 401A can be used in most known lock-in applications in the frequency range 1Hz-50kHz. Its large dynamic range, low noise input, high sensitivity and auto-triggering reference input make it totally compatible with most experimental arrangements. However in some of the applications the ultra low noise Nanovolt Preamplifier type 431 has been included where the signal source is low impedance (< 1kΩ) and nanovolt sensitivity may be required. For detection of signals greater than 100nV it is generally unnecessary and may be left out.

6.1 light measurement (amplitude modulation)

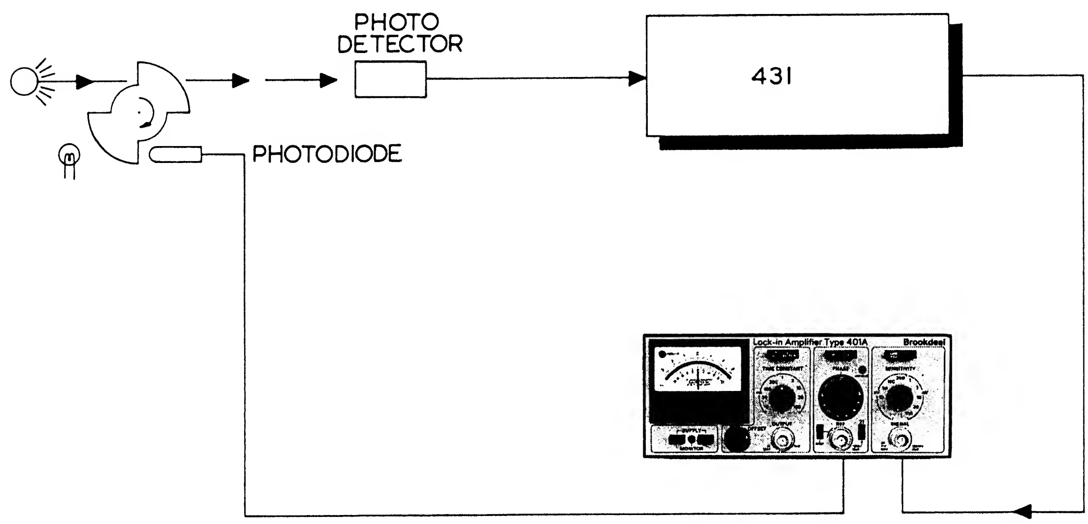


fig 19

NOTES: 431 preamplifier used for low impedance photodetectors such as thermopiles, InSb photocells, thermistors.

Reference photodiode is energised by REFERENCE BIAS in 401A.

6.2 light measurement (wavelength modulation)

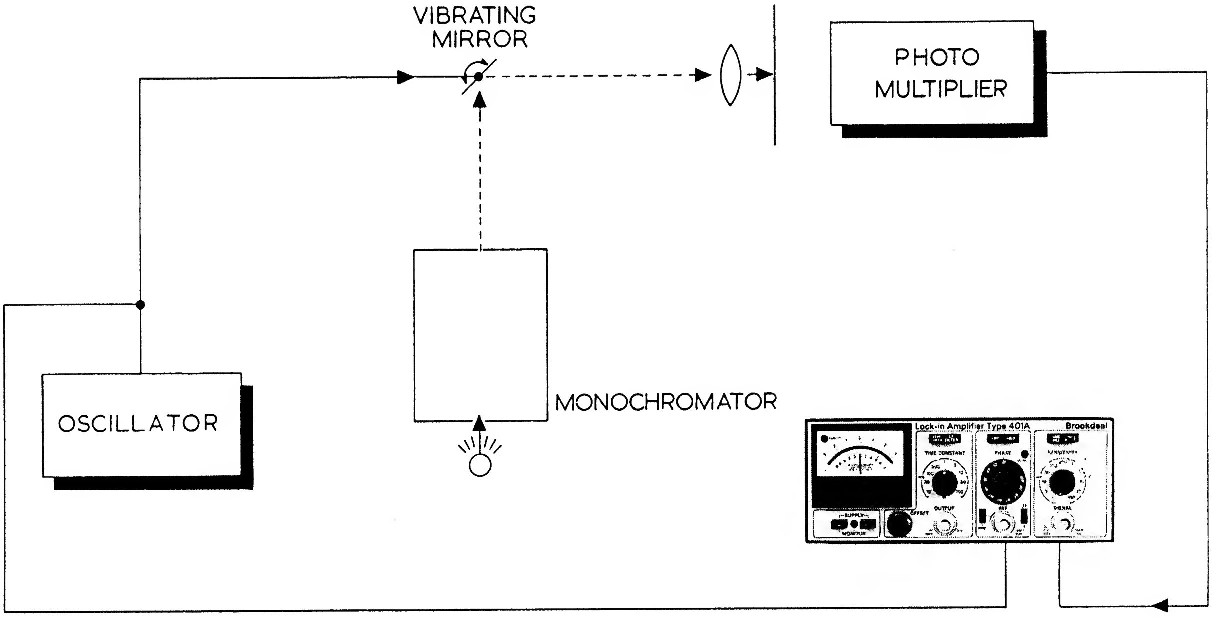


fig 20

NOTE: Frequency doubling may be used to improve discrimination.

6.3 temperature measurement (thermistor bridge)

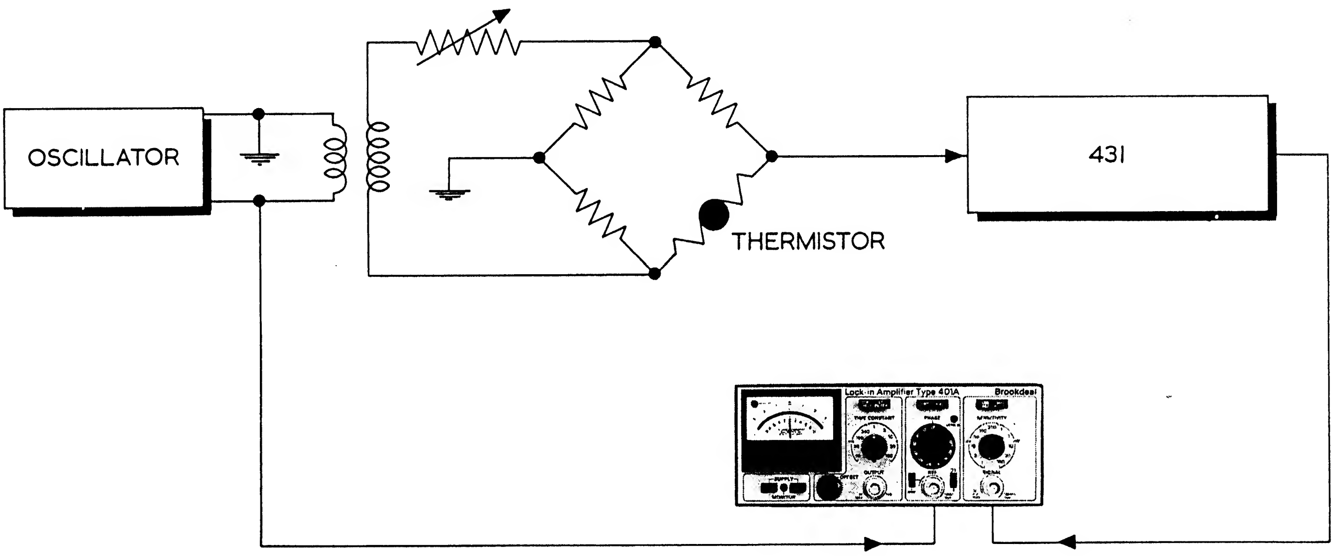


fig 21

NOTE: Low frequency (~ 20Hz) usually used to avoid reactive effects. Careful phase adjustment allows use of high frequency to avoid flicker noise.

6.4 displacement measurement (differential inductance)

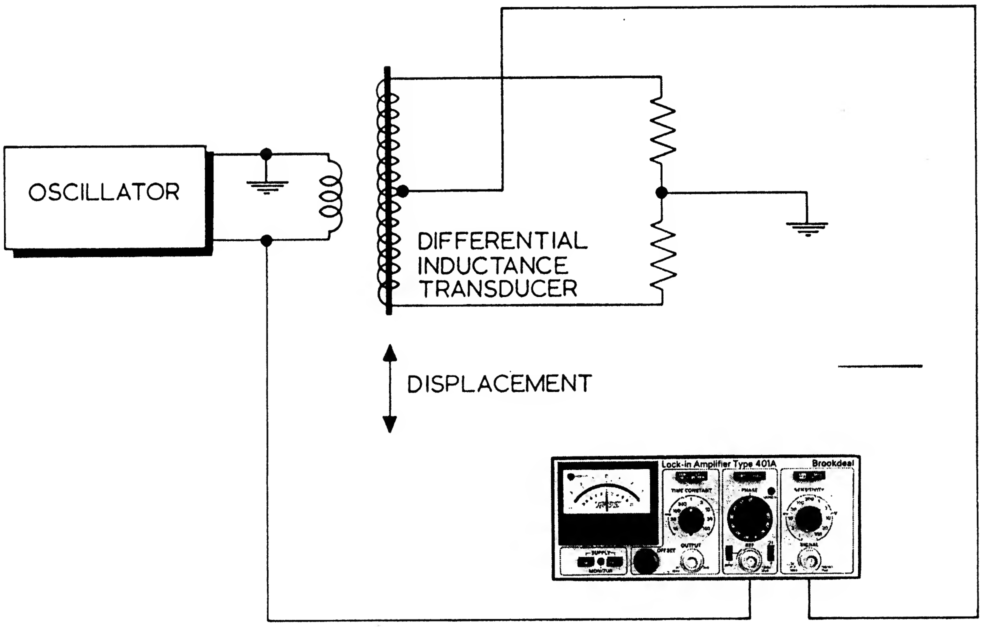


fig 22

6.5 displacement measurement (variable capacitance)

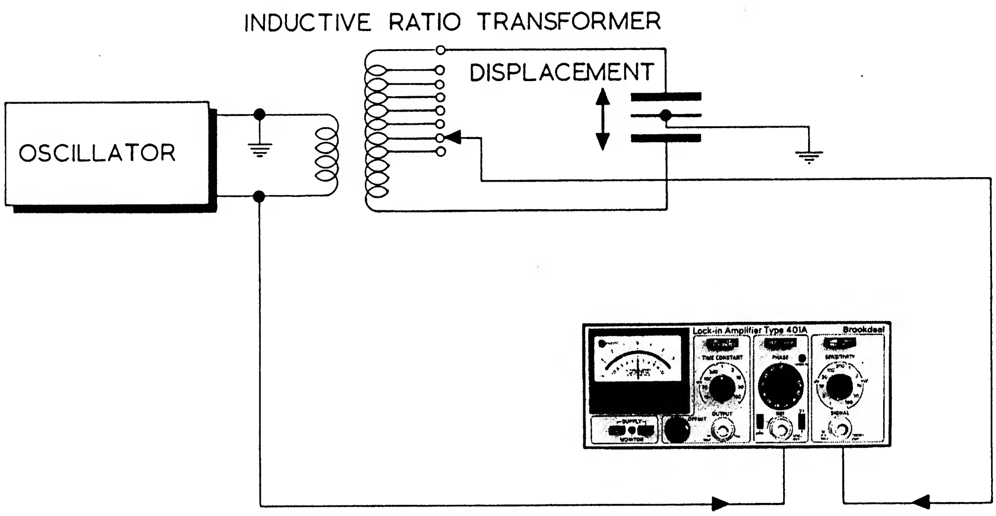


fig 23

NOTE: By using an inductive ratio transformer to null the output, very precise measurement of displacement can be made.

6.6 vibrating sample magnetometer

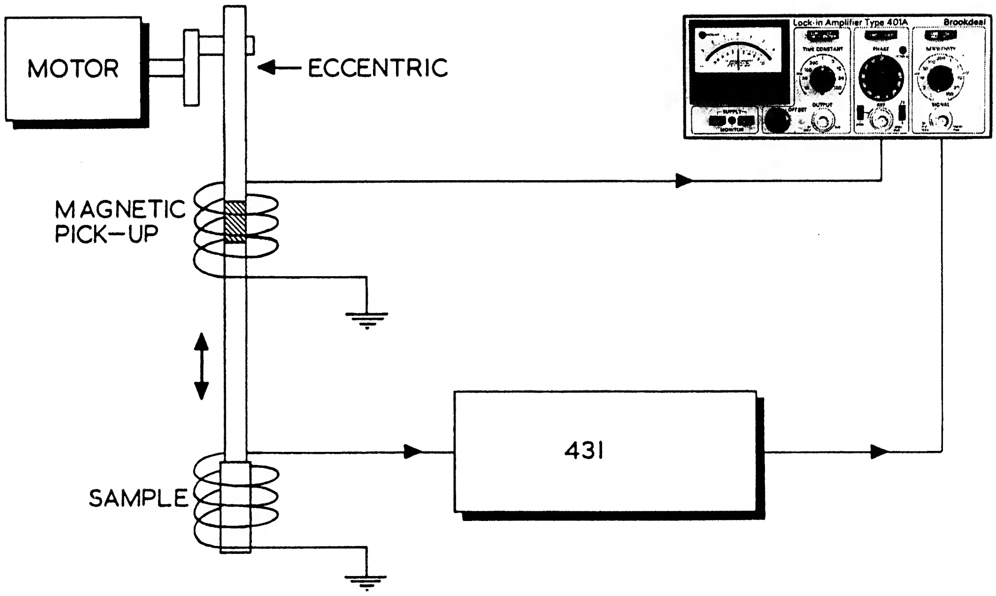


fig 24

6.7 microwave measurements

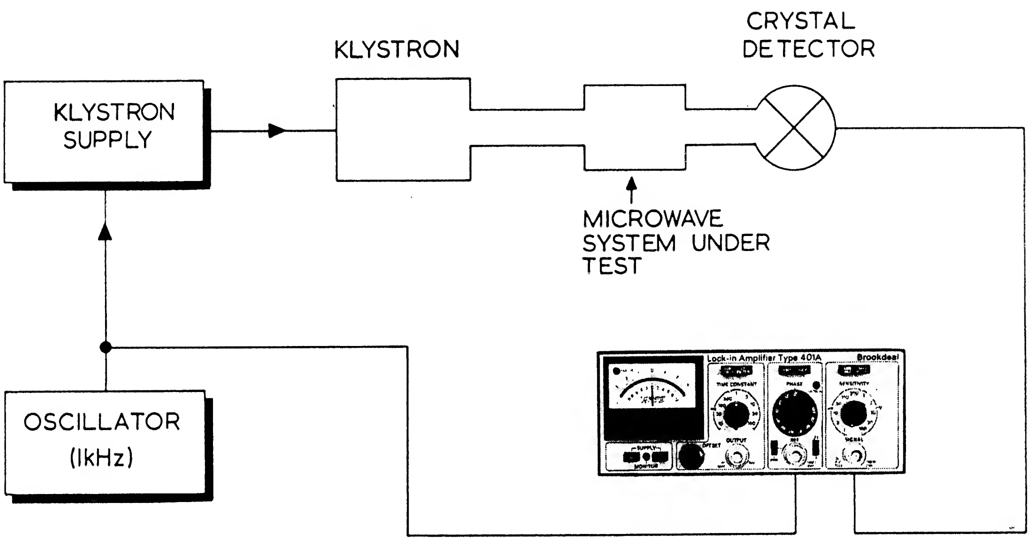


fig 25

NOTE: Many microwave measurements are carried out using 1kHz modulation and a tuned detector. Considerable improvement in sensitivity can be obtained using the 401A.

6.8 measurement of Hall effect

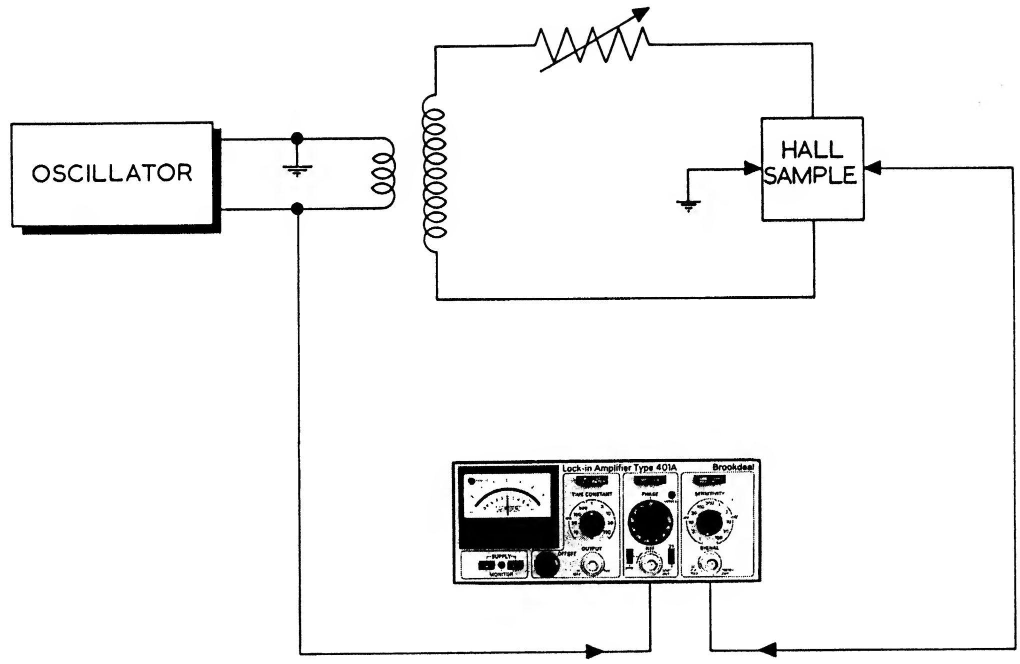


fig 26

NOTE: It is desirable to supply the input current from an isolating transformer so that a single-ended input may be used to measure the Hall voltage.

6.9 Auger spectroscopy

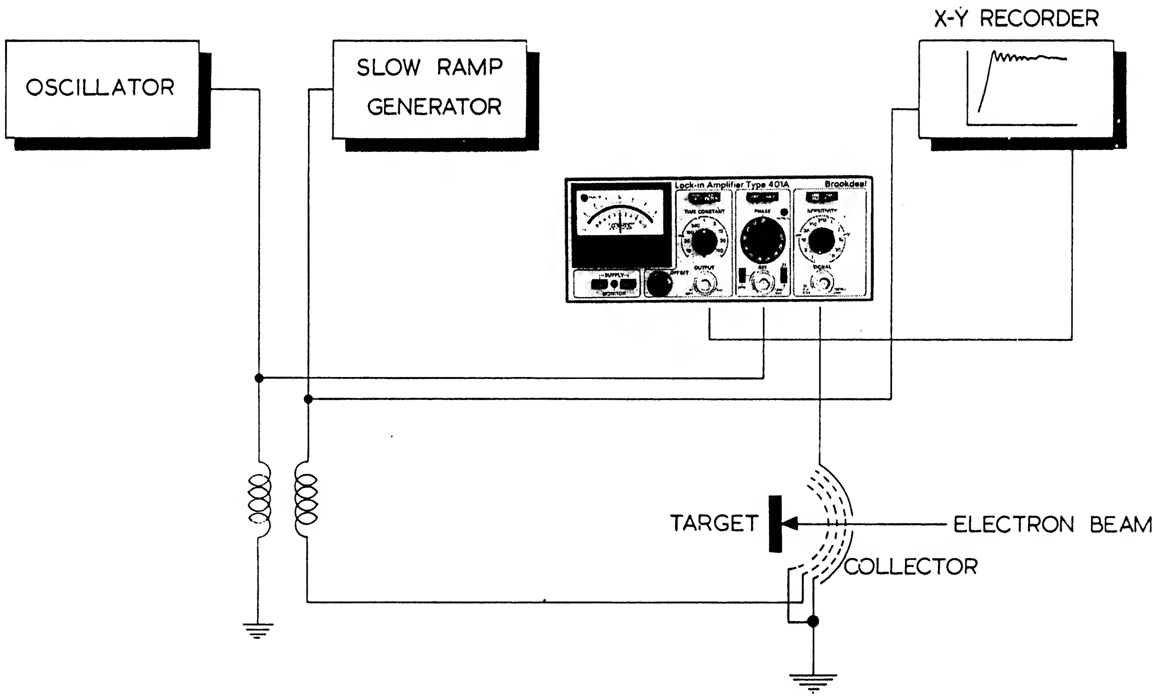


fig 27

NOTE: The spectrometer shown here is based on LEED optics and requires the reference of the 401A to be double frequency. Spectrometers using the cylindrical mirror analyser only require single frequency reference.

6.10 measurement of common-mode rejection of a differential amplifier

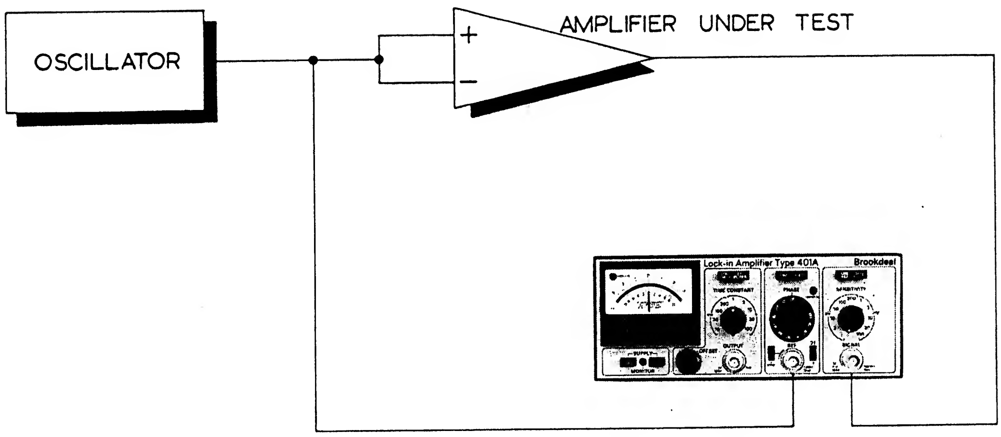


fig 28

NOTE: This system is capable of measuring ac cmr in excess of 140dB and because it is phase sensitive can discriminate the real and imaginary balance components.

7 circuit description

The relationship between the various circuit blocks of the 401A is shown in figure 29. The positions of the various boards are shown in figure 30.

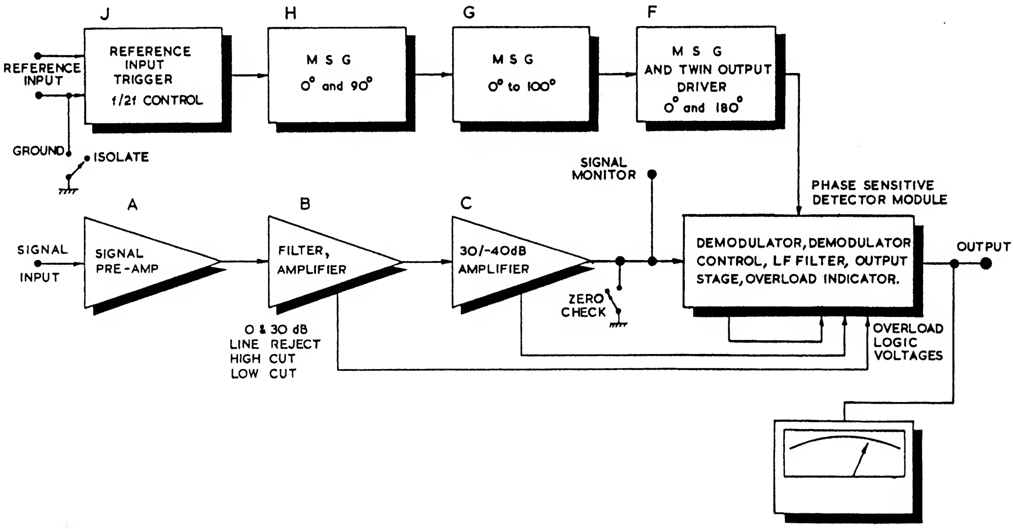
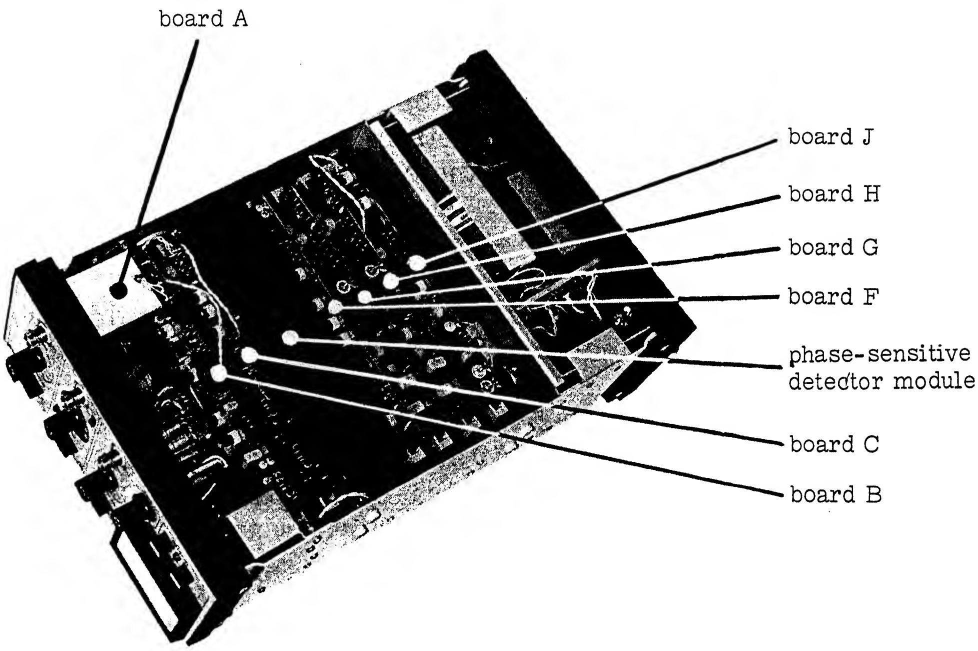


fig 29



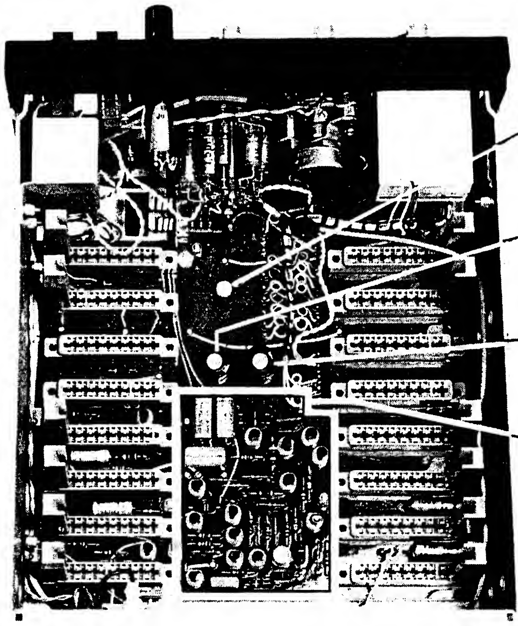


fig 30

7.1 front panel switching

(a) The SENSITIVITY control is a 3 pole switch which routes dc voltages to the gates of the gain switching fets on boards B and C.

(b) The TIME CONSTANT switch connects the appropriate filter capacitor to the output of the demodulator whilst connecting the other capacitors to the output of the buffer fets in the psd module so as to maintain the voltage across them at the correct level.

7.2 power supply stabiliser - mother board (K)

This is designed to have a low minimum voltage drop whilst providing short circuit protection.

It is supplied with dc from the plug-in power packs via pins 30 and 37. Q1, Q2 and Q3 form an emitter-coupled cascode combination feeding the complementary compound transistor pair Q4, Q6 (the series regulator). Overcurrent protection is provided by transdiodes Q15-Q17 which switch Q1 collector current back into the supply rail. The output voltage (18V) is divided by R11/R12 and compared with the voltage across

ZD1 and the base-emitter junction Q7. The circuit is started by current supplied directly from the input by D6 which is cut off in normal operation.

The voltage across the regulator is monitored by Q5 which operates LD2.

The +9V and -9V rails are obtained from the highly stable 18V output by the rail splitter Q8-Q12. The bases of Q8 and Q9 are connected to dissimilar potential dividers R13, R14 and R21, R20/22 whose values are so calculated that there will be equal voltages at their centre points when the supply is split in equal proportions. Any departure from this state unbalances Q8 and Q9. This unbalance is amplified and fed to the series regulator Q12 in such a sense as to oppose the unbalance. High loop gain is maintained by feeding the collector of Q9 from the active load Q10, R17. R18 limits the current which can be drawn from the splitter and reduces the dissipation in Q12.

7.3 clamping circuit - mother board (K)

Q14 etc forms a clamp across the psd current source which is operative under two conditions:-

(a) for 20 seconds after switch-on.

(b) when the instrument is on but no reference voltage is being supplied. 10 seconds after the application of a suitable reference voltage the clamp comes off.

7.4 high frequency offset compensation - mother board (K)

High frequency breakthrough in the demodulator is nulled by injecting the reference waveform via two SIT capacitors.

7.5 signal preamplifier - board A

The signal input is protected by the collector-base junctions of Q1, Q2, Q5-10 which ensure a low overall leakage current. Q3 is a specially selected fet supplied by current source Q4 etc.

7.6 filter amplifier - board B

The amplifier consists of:-

(a) a high-performance operational amplifier Q2, Q3, Q4, Q5, Q7 and Q8, with closed-loop gain switchable between 0dB and 30dB by switching-fets Q1 and Q6.

(b) a simple tunable null network which can be switched in or out by switching-fets Q9 and Q11.

(c) a buffer Q10, Q12.

(d) high cut filter with pole location switchable by Q13.

(e) low cut filter with pole location switchable by Q14.

(f) a prefilter overload sensor Q15-Q16 feeding logic levels out via D14.

7.7 30dB/-40dB amplifier - board C

The amplifier consists of:-

(a) a high performance operational amplifier Q1-Q6 with closed loop gain switchable from 0 to 30dB in 10dB steps by switching-fets Q7, Q9, Q11, Q13.

(b) an amplifier output overload sensor Q17, Q18 feeding logic levels out via D9.

(c) a 0 to -40dB attenuator switchable by switching-fets Q8, Q10, Q12, Q14, Q15.

(d) a switching-fet Q16 which isolates the signal channel when the ZERO CHECK button is depressed.

7.8 reference input trigger, f/2f control, untriggered indicator - board J

The circuit formed by the collector-base junctions Q1-Q6 and D1 and D2 provides input protection against both common-mode and differential signals. Q7-Q15 etc form a differential amplifier whose output at the collector of Q15 is fed to the Schmitt trigger Q17, Q18. The mean level of this output is maintained at the Schmitt trigger level by a dc feedback loop connected via pins (11) and (3).

The two Schmitt outputs are differentiated and connected via diodes D20, D21 to the next stage. For single frequency operation only one output is used, both are used in the 2f mode.

The UNTRIGGERED indicator circuit consists of a full-wave peak sensing circuit formed by Q19-Q23.

7.9 mark-space generator - boards G, H and part of F

The three mark-space generators (one on each of the boards F, G and H) are identical and the function of each is to generate a rectangular waveform of a desired mark/space ratio when triggered by an input waveform. The block schematic of figure 31 shows the principle of operation.

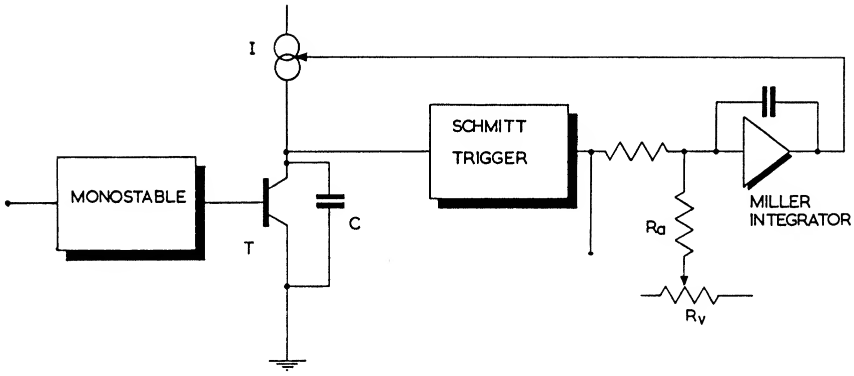


fig 31

The capacitor C charges at a rate determined by the current generator I and discharges when a positive input pulse causes the monostable to change state and saturate Q. When the voltage across C rises to a certain level, (a in figure 32) the Schmitt trigger changes state and remains 'on' until C discharges as above (b in figure 32). The Miller integrator is also driven by the Schmitt trigger and the output is used to control the current

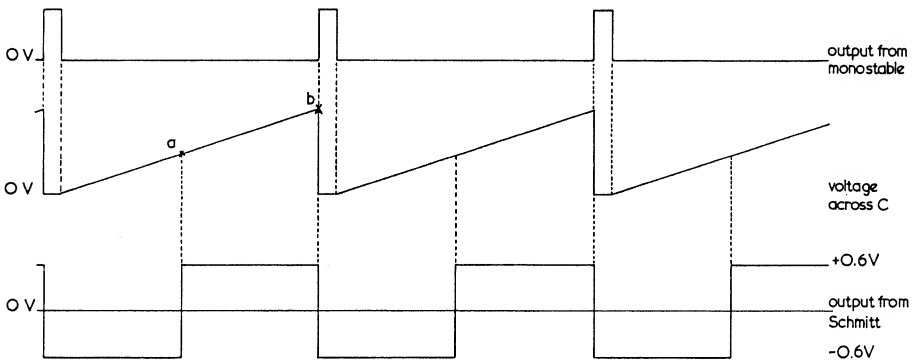


fig 32

generator I. When the output of the Schmitt has a unity mark/space ratio, its mean level is zero. A mark/space ratio other than unity may be obtained by introducing an offset current at the input to the operational integrator and this is done via R_V and R_a. The input stage of each msg consists of a monostable formed by Q1 and Q2 etc, Q1 being held in the 'on' state until a positive trigger input pulse is applied to C1. The current generator is formed by Q4 and Q5 etc, and this charges C4 when Q3 is switched off. Q6 and ZD1 act as a catching circuit which limits the voltage to which C4 can charge. Q7 is a low-leakage input buffer for the Schmitt trigger formed by Q8 and Q9. The output of the Schmitt appears at pin 8. The integrator is formed by Q10 to Q13 etc, and the output fed back to the

current generator via D12. RV1 adjusts the output mark/space ratio of the msg to unity in the absence of an input to pin 11 (board F). When mark/space ratios other than unity are required, voltage offsets are introduced via pin 11. The 0°-100° variable phase shift facility is provided by introducing an offset voltage as described in section 4.4.2 (page 20) to the msg (board G) via pin 11.

7.10 twin output driver - board F

The msg output is fed to the phase splitter Q16, Q17 of which either output may be selected by clamping with either of Q14 or Q15, thus providing 180° switching. The selected output is diode-connected to the driver pair Q18, Q19.

7.11 Power supply types 4002 and 4003 - rectifier board

This board consists of a full-wave rectifier D1-4 followed by the low-pass filter C1-3, R1, 2.

In power pack 4003, the cell recharging current is supplied by the current generator Q1 etc. via pins 5 and 11.

8 parts list

8.1 components on board A (signal preamplifier)

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer	
R1	220	5		1/2		Piher	
R2	68k	"		1/8		"	
R3	100M	10		1/2	LHR05	Mullard	
R4	2k2	5		1/8		Piher	
R5	1k	"		"		"	
R6	1k	"		"		"	
C1	0.22µ	20	100		PMT2R		
C2, 3, 4	10µ	20	20				
Q1, 2, 5-10					SC108		
Q3					S1243N/090		*
Q4					BC184LC	Texas	
D1 - 5					1N4148	STC	

8.2 components on board B (filter amplifier)

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
R1	100k	5		1/8		Piher
R2	33k	"		"		"
R3	3k6	1		1/2	C5	Electrosil
R4	100k	5		1/8		Piher
R5	10M	"		1/2		"
R6	22k	"		1/8		"
R7	33k	"		"		"
R8	SIT	1		1/2	C5	Electrosil
R9	110k	"		"	"	"
R10	100k	5		1/8		Piher
R11	6k8	"		"		"
R12	10M	"		1/2		"
R13	220	"		1/8		"
R14	33k	"		"		"
R15	22k	"		"		"
R16	22k	"		"		"
R17	68k	"		"		"
R18	10M	"		1/2		"
R19	10k	"		1/8		"
R20	2k2	"		"		"

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
R21	100k	5		1/8		Piher
R22	22k	"		"		"
R23	10M	"		1/2		"
R24	100k	"		1/8		"
R25	1M	"		1/2		"
R26	9k1	1		"	C5	Electrosil
R27	10M	5		"		Piher
R28	100k	"		1/8		"
R29	180k	"		"		"
R30	10M	"		1/2		"
R31	100k	"		1/8		"
R32	100k	"		"		"
R33	10M	"		1/2		"
R34	120k	"		1/8		"
R35	180k	"		"		"
R36	120k	"		"		"
R37	180k	"		"		"
RV1	33k				MPDPC269	ITT
C1	10µ	-20, +50	15		Printilyt	Wima
C2	15p	5			S/M radial	RBS
C3	0.1µ	20	100		PMP	STC
C4	0.22µ	"	"		"	"
C5	0.1µ	"	"		"	"
C6	330p	5	400		TFF	ITT
C7	1µ	-20, +100	35		Printilyt	Wima
C8	3300p	20			disc ceramic	ITT
C9	10µ	-20, +50	15		Printilyt	Wima
C10	0.01µ	20	100		PMP	STC
Q1					2N3819	Texas
Q2, 3, 4					BC184LC	" *
Q5					BC214LC	"
Q6					2N3819	"
Q7, 8					BC184LC	"
Q9					2N3819	"
Q10					BC184LC	"
Q11, 12, 13, 14					2N3819	"
Q15, 16					BC214LC	"
D1 - 14					1N4148	STC

8.3 components on board C (30/-40dB amplifier, zero check)

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
R1	33k	5		1/8		Piher
R2	6k8	"		"		"
R3	33k	"		"		"
R4	100k	"		"		"
R5	220	"		"		"
R6	10M	"		1/2		"
R7	22k	"		1/8		"
R8	33k	"		"		"
R9	33k	1		1/2	C5	Electrosil
R10	100k	5		1/8		Piher
R11	10M	"		1/2		"
R12	100k	"		1/8		"
R13	15k	1		1/2		Electrosil
R14	10M	5		"		Piher
R15	100k	"		1/8		"
R16	10M	"		1/2		"
R17	4k7	1		"		Electrosil
R18	10M	5		"		Piher
R19	10M	"		"		"
R20	100k	"		1/8		"
R21	100k	"		"		"
R22	1k5	1		1/2		Electrosil
R23	10M	5		"		Piher
R24	100k	"		1/8		"
R25	10M	"		1/2		"
R26	100k	"		1/8		"
R27	470	1		1/2		Electrosil
R28	220	"		"	C5	"
R29	10M	5		"		Piher
R30	100k	"		1/8		"
R31	10M	"		1/2		"
R32	100k	"		1/8		"
R33	180k	"		"		"
R34	100k	"		"		"
R35	180k	"		"		"
R36	180k	"		"		"
R37	120k	"		"		"
R38	120k	"		"		"
R39	6k8	"		"		"
R40	2k2	"		"		"
R41	10M	"		1/2		"
R42	SIT	1		"		Electrosil
C1	22p	2	350		S/M	Lemco
C7	0.01μ	20	400		PMP	STC

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
Q1, 2					BC184LC	Texas
Q3					BC214LC	"
Q4, 5, 6					BC184LC	"
Q7-16					2N3819	"
Q17, 18					BC214LC	"
D1-9					1N4148	STC

8.4 <u>components on board F (msg with twin output driver)</u>

R1	10k	5		1/8		Piher
R2	120k	"		"		"
R3	47k	"		"		"
R4	15k	"		"		"
R5	47k	"		"		"
R6	3k3	"		"		"
R7	1M			1/2		"
R8	4k7	5		1/8		"
R9	1M	"		1/2		"
R10	270k	"		1/8		"
R11	150k	"		"		"
R12	27k	"		"		"
R13	13k	"		"		"
R14	1k8	"		"		"
R15	8k2	"		"		"
R16, 17	47k	"		"		"
R18	36k	"		"		"
R19, 20	47k	"		"		"
R21	2M2	"		"		"
R22	220k	1		1/2		Electrosil
R25	8M2	5		1/2		Piher
R26	100k	"		1/8		"
R27	2M2	"		"		"
R28	68k	"		"		"
R29	180k	"		"		"
R30	8k2	"		"		"
R31	18k	"		"		"
R32	8k2	"		"		"
R33	180k	"		"		"
R34	10k	"		"		"
R35	220Ω	"		"		"
R36, 37	10k	"		"		"
R40	82k	5		1/8		Piher
RV1	47k				MPD/PC	STC

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer	
C1	47p	5			S/M radial	Lemco	
C2	82p	"			"	RBS	
C3	1000p	20			831269 x 4731 R	ITT	
C4	470p	20			269 x 4729H	"	
C5	0.47µ	20	100		PMP	STC	
C6	68p	5	350		S/M radial	RBS	
C7, 8	10µ	-20, +100	15		Printilyt	Wima	
C9	0.47µ	20	100		PMP	STC	
C10	0.022µF	20	400		"	"	
Q1, 2					BC214LC	Texas	
Q3					2N4254	"	
Q4					BC184LC	"	
Q5					BC214LC	"	
Q6					BC184LC	"	
Q7					2N3819	"	*
Q8, 9					BC184LC	"	
Q10, 11					"	"	*
Q12-15					BC214LC	"	
Q16, 17					BC184LC	"	
Q18, 19, 20					BC214LC	"	
D1, 2, 3					1N4148	STC	
D4,5,6, 7					"	"	*
D8-19					"	"	
ZD1					HS7051	STC	
ZD2					HS7047	"	

8.5 <u>components on boards G and H (mark-space-generator (msg))</u>

R1	10k	5		1/8		Piher
R2	120k	"		"		"
R3	47k	"		"		"
R4	15k	"		"		"
R5	47k	"		"		"
R6	3k3	"		"		"
R7	1M	"		"		"
R8	4k7	"		"		"
R9	1M	"		1/2		"
R10	270k	"		1/8		"

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
R11	150k	5		1/8		Piher
R12, 13	27k	"		"		"
R14	1k8	"		"		"
R15	8k2	"		"		"
R16, 17	47k	"		"		"
R18	27k	"		"		"
R19, 20	47k	"		"		"
R21	2M2	"		1/2		"
R22	220k	1		"	C5	Electrosil
R23	330k	5		"		Piher
R25	8M2	5		1/8		Piher
R26	100k	"		"		"
R27	2M2	"		1/2		"
R28	68k	"		1/8		"
RV1	47k				MPD/PC	STC
C1	47p	5			S/M radial	RBS
C2	82p	"			"	"
C3	1000p	20	400		TFF	Waycom
C4	470p	"	"		"	"
C5	0.47µ	"	100		PMP	STC
C6	68p	-20, +50	150		S/M radial	RBS
C7, 8	100µ	20	15		Printilyt	Waycom
C9	0.47µ	"	100		PMP	STC
Q1, 2					BC214LC	Texas
Q3					2N4254	"
Q4					BC184LC	"
Q5					BC214LC	"
Q6					BC184LC	"
Q7					2N3819	Wel. *
Q8, 9					BC184LC	Texas
Q10, 11					"	" *
Q12, 13					BC214LC	"
D1,2,3					1N4148	STC
D4,5, 6, 7					"	" *
D11, 12					1N4148	STC
ZD1			ZF5.1		HS7051	STC
ZD2			ZF4.7		HS7047	"

8.6 components on board J (reference input amplifier and trigger)

circuit ref	components value	tol %	volts wkg	power rtg. W	type	manufacturer
R1,2	10M	5		1/2		Piher
R3	5k1	"		"		"
R4	10k	"		1		"
R5	5k1	"		1/2		"
R6	27k	"		1/8		"
R7	18k	"		"		"
R8	2k2	"		"		"
R9,10	1k2	"		"		"
R11	18k	"		"		"
R12	1k2	"		"		"
R13	27k	"		"		"
R14	56k	"		"		"
R15	470	"		"		"
R16	3k3	"		"		"
R17	470	"		"		"
R18	15k	"		"		"
R19	1M	"		"		"
R20	100k	"		"		"
R21	15k	"		"		"
R22	56k	"		"		"
R23	SIT	"		1/8 or 1/2		"
R24	3k9	"		1/8		"
R25	18k	"		"		"
R26	47k	"		"		"
R27	180k	"		"		"
R28	82k	"		"		"
R29	180k	"		"		"
R30	82k	"		"		"
R31	3M9	"		"		"
R32	680k	"		"		"
R33	18k	"		"		"
R34	120k	"		"		"
R35	39k	"		"		"
R36,37	10k	"		"		"
R38	100k	"		"		"
R39	SIT	"		"		"
RV1	47k				MPD/PC	STC

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
C1	0.1µ	20	100		PMP	STC
C2	47µ	"	10		Printilyt	Wima
C3	47p	5			S/M radial	Lemco
C4	1µ	20	100		PMP	STC
C5	0.047µ	20	250		"	"
C6, 7	100µ	20	15		Printilyt	Wima
C8, 9	47p	5			S/M radial	Lemco
Q1-6					BC184LC	Texas
Q7					2N3819	" *
Q8-12					BC184LC	"
Q13					2N3819	" *
Q14, 15					BC214LC	"
Q16,17,18					BC184LC	"
Q19, 20					BC214LC	"
Q21,22,23, 24					BC184LC	"
D1-21					1N4148	STC

8.7 <u>components on board K (mother board)</u>

R1	2k2	5		1/8		Piher
R2	12k	"		"		"
R3	22k	"		"		"
R4	82	"		"		"
R5	12	"		1/2		"
R6	SIT	1		"	C5	Electrosil
R7	680	5		1/8		Piher
R8	7k5	"		"		"
R9	680	"		"		"
R10	220k	"		"		"
R11	22k	1		1/2	C5	Electrosil
R12	18k	5		"	"	"
R13	22k	1		"	"	"
R14	10k	"		"	"	"
R15,16,17	10k	5		1/8		Piher
R18	47	"		1/2		"
R19	27k	"		1/8		"
R20	22k	1		1/2	C5	Electrosil
R21	10k	"		"	"	"
R22	SIT	"		"	"	"
R24	27k	5		1/8		"
R25	10k	"		"		Piher

circuit ref	component value	tol %	volts wkg	power rtg.W	type	manufacturer
R26	3k3	5		1/8		Piher
R27	330k	"		"		"
R28	1M	"				"
R29	SIT	1		"	C5	Electrosil
R30	SIT	"		"	"	"
R31	2k2	5		1/8		Piher
R32	10k	"		"		"
R34	100k	"		"		"
R35	1k	"		1/2		"
RV1, 2	330k				MPD/PC	STC
C1	0.1μ	5	100		PMP	STC
C2	1μ	20	"		"	"
C3, 4	68p	5			S/M radial	RBS
C5, 6	100μ	20	15		Printilyt	Wima
C7	22μ	-20, +100	16		"	"
C8	10μ	-20, +100	35		"	"
C10, 11	1μ	10	100		TFM	"
C12	47μ	-20, +100	10		Printilyt	"
Q1					BC182LB	Texas
Q2, 3					BC184LC	"
Q4					BC214LC	"
Q5					BC182LB	"
Q6					2N3053	"
Q7					BC182LB	"
Q8, 9					BC184LC	"
Q10					BC214LC	"
Q11					BC184LC	"
Q12					BC182LB	"
Q13, 14					BC214LC	"
Q15, 16, 17					BC184LC	"
D1-7, 10					1N4148	ITT
ZD1					HS7091	ITT
ZD2, 3, 4					HS7039	"
	switch assemblies					Lipa and Isostat

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer

8.8 front panel controls, internal fuse

Brookdeal part No.						
zero offset control						
01351	10k linear potentiometer				10T	R/S
variable phase shift control						
01318	25k linear potentiometer				E	Plessey
time constant switch assembly						
00126	1000p	10			TFF	Wima
00136	4700p	5	400		"	"
00140	0.015µ	10	160		TFM	"
00160	0.047µ	"	400		"	"
00165	0.15µ	"	160		"	"
00174	0.47µ	"	100		"	"
00180	1.5µ	"	"		"	"
00185	4.7µ	"	"		"	"
01099	100mA slow-blow				fuse	

8.9 power supplies

4002 (ac power pack)

R1, 2	150	5		1/2		Piher
C1, 2, 3	250µ	-10, +50	64			Mullard
D1-4, 8					BYX36-600	Mullard

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
Brookdeal part no.						
00305	voltage selector switch					Switchcraft
00393	transformer				40/586	Avel
01099	fuse 100mA				20mmx5mm	Beswick

4003 (rechargeable power pack)

circuit ref	component value	tol %	volts wkg	power rtg. W	type	manufacturer
R1, 2	150	5		1/2		Piher
R3	10k	"		"		"
R4	56	"		"		"
C1,2,3	250µ	+50, -10	64			Mullard
Q1					40362	RCA
D1-5					BYX36-600	Mullard
D6, 7					1N4148	Texas
D8					BYX36-600	Mullard
D9					1N4148	Texas
Brookdeal part no.						
00305	voltage selector switch					Switchcraft
00393	transformer				40/586	Avel
01099	fuse 100mA				20mmx5mm	Beswick

* Items marked thus should be obtained from Brookdeal Electronics Ltd., since they are either selected versions of parts available from other manufacturers or are specially made to Brookdeal designs. When ordering such parts please quote instrument type, serial number and circuit reference.

9 appendices I and II

On the following pages are reproduced test procedures which may be used for checking and setting up the instrument.

Appendix I is the instrument test procedure which may be used in cases wherein such repairs have to be carried out in the field, that readjustments are necessary.

The final test procedure described in appendix II is included here for use by overseas agents when checking newly delivered goods, customers standards departments etc.

appendix 1

INSTRUMENT TEST PROCEDURE
401A LOCK-IN AMPLIFIER

The following test equipment is required for this test.

Note that "nearest preferred value" refers to E24 series.

TEST EQUIPMENT

500V insulation tester

EXAMPLE EVERSHED AND VIGNOLES MEGGER

High impedance digital dc voltmeter
resolution 1mV
accuracy 0.1%
maximum reading > 1.000V

EXAMPLE IE DSV4

Oscilloscope

bandwidth dc to 1MHz
sensitivity 5mV/cm - 5V/cm

EXAMPLE TEKTRONIX 544 + 1A1 PLUG-IN

Signal Generator

frequency range 1Hz - 100kHz
output 1mV - 1Vrms
sine and square wave

BROOKDEAL TYPE 471

Attenuator

attenuation 0-100dB

EXAMPLE MARCONI TF1073A

ac voltmeter

frequency range 10Hz - 100kHz
sensitivity 1mV - 1V

EXAMPLE HEWLETT PACKARD 400E

Variable line transformer 0V-260V

EXAMPLE REGULAC RB2-M

Phase shifter

frequency range 10Hz-50kHz
phase shift 0-90°
accuracy 1°

EXAMPLE BROOKDEAL TYPE 422

401A special purpose oscillator

ORDER OF THE BOARDS

Order of the plug-in boards from the back to the front of the 401A is given below.

J	reference input amplifier and trigger.
H	MSG I.
G	MSG II.
F	MSG with twin output driver.
	phase sensitive detector module.
C	30/-40dB amplifier.
B	filter amplifier.

The signal preamplifier board A is mounted on the front panel behind the SIGNAL socket.

TEST PROCEDURE

1. Plug a tested 4003 rechargeable ac power pack into the back of the 401A. Measure the following line plug impedances

a) earth to frame < 0.5Ω
b) earth to line > 100MΩ
c) earth to neutral > 100MΩ
d) live to neutral > 100MΩ with LINE switch off
(a)–(d): use megger

e) live to neutral about 300Ω on 230V range
f) live to neutral about 75Ω on 115V range
(e)–(f): with LINE switch on

g) SIGNAL BNC outer to frame <0.5Ω
h) SIGNAL MONITOR, REFERENCE, OUTPUT BNC outers to frame > 100MΩ
i) REFERENCE BNC outer to OUTPUT BNC outer > 100MΩ with REFERENCE OUTER switch in ISOLATE position.
j) REFERENCE BNC outer to OUTPUT BNC outer <0.5Ω with REFERENCE OUTPUT switch in GROUND position.

2. Fuse checks

Check that the 4003 plug-in is fused with 100mA slow-blow fuse. Check that the 401A is fused with 100mA slow-blow fuse. (This fuse is to be found on the plug bracket at the rear of the 401A).

3. Power stabiliser adjustments

a) Select 230V on the 4003 VOLTAGE SELECTOR switch. Plug the '401A dummy load' board into any one of the eight sets of edge connectors on the mother board and apply power from the line. Set the LINE switch to 'on'. Check that the MONITOR indicator lights. Set the BATT switch to 'on.

b) Measure the dc voltage between pins 14 and 16 of any one of the eight sets of edge connectors. Put a resistance box in place of R6 (on the track side of the mother board) and adjust it to make this voltage 18V ±50mV. Solder in the required value.

c) Measure the dc voltage between pins 15 and 16 of any one of the eight sets of edge connectors. Put a resistance box in place of R22 (again on the track side of the mother board) and adjust it to make this voltage 9V ±50mV. Solder in the required value.

d) Check that the ripple and noise between pins 15 and 16 is less than 2mV (use ac coupled oscilloscope, 5mV/cm sensitivity). Set the LINE and BATT switches to off and remove the '401A dummy load' board.

e) Plug a set of tested boards into the appropriate positions and set the LINE and BATT switches to on. Check that the dc voltage between pins 14 and 16 of any one of the eight sets of edge connectors is 18V ±50mV and that the dc voltage between pins 15 and 16 is 9V ±50mV.

4. Reference channel preliminary checks

a) Set:

REF OUTER	isolate	
OFFSET	immaterial	
TIME CONSTANT	10ms	
ZERO CHECK	normal	
LF FILTER	off	
PHASE	0°, 0°, 0°	
SENSITIVITY	100mV	
LINE REJECT	off	
5kHz HI-CUT	off	
2f/f	f	
LINE	off	
BATT	off	
LF	off	These switches are to be
REF BIAS	off	found inside the 401A

Connect the white wire from pin 40 on the mother board to pins A and B on board J. Do not connect the green wire from pin 39. Apply 200mVp-p sinewave at 50Hz to the REFERENCE input of the 401A. Observe the waveform at pin C on board J, using an oscilloscope, and adjust RV1 on board J to minimise the 50Hz signal at pin C (approximately 5mVp-p).

Disconnect the white wire from pin B and connect the green wire from pin 39 on the mother board to pin B on board J.

Reset:

LINE	on
BATT	on

Apply a 1Vp-p sinewave at 1kHz to the REFERENCE input of the 401A. Observe the waveform at pin 8 of the edge connector on board H on an oscilloscope. Check that it is a 1kHz square wave approximately 1.2Vp-p. Check that the UNTRIGGERED lamp is off. Reduce the oscillator output to zero and check that no square wave is present at pin 8 of the board H's edge connector Check that the UNTRIGGERED lamp is now on.

b) Reset the oscillator output to 1Vp-p and observe the waveform at pin 8 of the edge connector of board H. Check that is is a 1kHz squarewave of approximately 1.2Vp-p and with mark/space ratio of approximately 1:1.

Reset: FIXED PHASE 90°, 0°

Check that the mark/space ratio changes to approximately 3:1

Reset: FIXED PHASE 0°, 0°

c) Observe the waveform at pin 8 of the edge connector of board G. Check that it is a 1kHz squarewave approximately 1.2Vp-p and with mark/space ratio of approximately 1:1.

Reset: VARIABLE PHASE 90°

Check that the mark/space ratio changes to approximately 3:1.

Reset: VARIABLE PHASE 0°

d) Trigger the oscilloscope externally from the reference input signal. Observe the waveforms at pins 6 and 7 of the edge connector of board F. Check that the waveforms are two 1kHz squarewaves with 180° phase difference between them.

Reset: FIXED PHASE 0°, 180°

Check that the two squarewaves both change phase by 180°.

Reset: FIXED PHASE 0°, 0°

Remove the reference input signal

e) Measure the dc voltage between the inner and the outer of the REFERENCE socket with the high impedance dc voltmeter. Check that it is 0V.

Reset:

REF BIAS	on

Check that the voltage is now 9V ±50mV (inner positive).

Reset:

REF BIAS	off

Remove the dc voltmeter.

5. <u>Signal channel adjustments</u>

a) Set:

REF OUTER	isolate
OFFSET	approx central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^{\circ}, 0^{\circ}, 0^{\circ}$
SENSITIVITY	30µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Put board B on an extender board. Using a clip lead join pin A on board B to 0V (pin D on board B). Measure the dc voltage at the test point (pin marked TP on board B) using a high impedance dc voltmeter. Put a resistance box in place of R8 and adjust it to make this voltage 0V±10mV.

Reset:

SENSITIVITY	100µV

Check that the voltage is still 0V±10mV, if not readjust R8 slightly. Finally check the voltage in the 30µV position. Solder in the required value. Plug board B into position. Remove the clip lead and the voltmeter.

Note: It may be necessary to use two parallel SIT's to achieve the required accuracy.

b) Reset:

SENSITIVITY	1µV

Put board C on an extender board. Using a clip lead join pin A on board C to 0V (pin C on board C). Measure the dc voltage at the test point (pin marked TP on board C) using a high impedance dc voltmeter. Put a resistance box in place of R42 and adjust it to make this voltage 0V±10mV. Reset the SENSITIVITY to 3µV and 10µV and note the voltage in these two positions. If necessary readjust R42 so that

the voltage never departs from 0V by more than ±20mV in switching from 1μV to 10μV. Solder in the required value. Remove the clip lead and the voltmeter.

Note: It will be found necessary to use two parallel SIT's to achieve the required accuracy.

6. Signal channel checks

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	30μV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	off
BATT	off
LF	off
REF BIAS	off

Solder the four wires coming off board A to the pins marked -, D, A, + on board B as follows:-

blue	to	-
brown	to	D
yellow	to	A
orange	to	+

Using a green and white twisted pair of wires connect pins B and C on board B to pins A and C on board C (green to C's, white to A and B).

Reset:

LINE	on
BATT	on

Apply approximately 1V p-p sinewave at 1kHz to the SIGNAL input of the 401A via an attenuator. Using a x 1 oscilloscope probe connect the output of board B (pin B) to the input of the ac voltmeter set to the -10dB (0.3V) range. Set the attenuator to 30dB and adjust the oscillator output to get 0dB on the voltmeter.

Reset:

SENSITIVITY	100μV

Reset the attenuator to 0dB and check that the voltmeter reads 0dB±0.1dB.

b) Reset the oscillator frequency to 5kHz and check that the voltmeter reads 0dB.

Reset:

5kHz HI-CUT	on

Check that the voltmeter reads not less than -3dB.

Reset:

5kHz HI-CUT	off

c) Reset the oscillator frequency to 50kHz and check that the voltmeter reads not less than -3dB.

d) Reset the oscillator to 50Hz and check that the voltmeter reads 0dB ±0.1dB.

Reset:

LINE REJECT	on

Adjust the potentiometer on board B to get the minimum reading on the voltmeter. Check that at this point the voltmeter reads less than -30dB.

Reset:

LINE REJECT	off

e) Transfer oscilloscope probe from the ac voltmeter to a dc coupled oscilloscope. Adjust the oscillator output to give 1Vp-p on the oscilloscope. Reset the oscillator frequency to 5Hz and check that the output of board B as seen on the oscilloscope is not less than 0.7Vp-p.

f) Reset the oscillator frequency to 1Hz. Check that the output of board B is now less than 0.7Vp-p.

Reset:

LF	on

Check that the output of board B is now not less than 0.7Vp-p.

g) Reset the oscillator frequency to 1kHz. Using an oscilloscope probe connect the output of board C (pin B) to the input of the ac voltmeter set to the -50dB (3mV) range.

Reset:

SENSITIVITY	100mV

Adjust the oscillator output so that the voltmeter reads 0dB. Using the following attenuator, SENSITIVITY, and voltmeter range settings check that the voltmeter reads 0dB ±0.1dB:

Attenuator dB	SENSITIVITY	Range dB(mV)
10	30mV	-50 (3)
20	10mV	"
30	3mV	"
40	1mV	"
50	300µV	"

60	100μV	-50(3)
"	30μV	-40(10)
"	10μV	-30(30)
"	3μV	-20(100)
"	1μV	-10(300)

h) Press the ZERO CHECK and check that the reading on the ac voltmeter falls to zero. Remove the SIGNAL input and the scope probe.

7. LF Filter check

Apply 1Vp-p sinewave at 100Hz to the REFERENCE input.

Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Observe the waveform at the OUTPUT socket using an oscilloscope triggered from the REFERENCE input. Check that the 100Hz reference breakthrough is less than 50mVp-p.

Reset:

LF FILTER	on

Check that the reference breakthrough is no longer present, ie the output is pure dc.

8. Meter adjustments

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	on
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	off
BATT	off
LF	off
REF BIAS	off

Set the mechanical zero on the meter.

b) Reset:

LINE	on
BATT	on

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control until the dc voltmeter reads +1V ±2mV. Put a resistance box set to 10kΩ in place of R30 (on the track side of the mother board). Adjust the resistance box so that the meter on the 401A reads exactly +1V. Solder in the required value.

Note: It will almost certainly be necessary to use two parallel SIT's. R29 can be used in parallel with R30.

Rotate the OFFSET control until the dc voltmeter reads -1V ±2mV. Check that the meter on the 401A reads -1V ±10mV.

9. <u>Output impedance check</u>

Set:

REF OUTER	isolate
OFFSET	approx central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	on
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control until the dc voltmeter reads +1V ±10mV. Connect a 1kΩ resistor in parallel with the OUTPUT socket and check that the dc voltage falls to 500mV ±10%. Remove the 1kΩ resistor.

10. <u>Output protection check</u>

Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	on
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	100mV

LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control until the dc voltmeter reads +1V ±10mV. Remove the lead from the OUTPUT socket to the dc voltmeter. Set the Regulac at its lowest voltage and connect its output to the OUTPUT socket: live to inner, earth to outer, neutral unconnected. Increase the Regulac setting to 20Vrms and leave for 10 seconds or so. Remove and replace the lead to the voltmeter. Check that the voltmeter reads +1V ±10mV.

11. 2f setting

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^{\circ}, 0^{\circ}, 0^{\circ}$
SENSITIVITY	10µV
LINE REJECT	off
5kHz HI-CUT	off
LF	off
REF BIAS	off
LINE	on
BATT	on
2f/f	2f

Apply 20mV p-p sinewave at 1kHz to the REFERENCE input of the 401A. Observe the signal at pin 8 on the edge connector of board H, using an oscilloscope, and check that it is two 2kHz squarewaves of unequal mark space ratio superimposed on one another. Put a resistance box in place of R23 on board J and adjust it so that the two squarewaves coincide. Leave the resistance box connected. Increase the oscillator output to 3V p-p. The two squarewaves will no longer coincide. Put a resistance box in place of R38 on board J and adjust it so that they do coincide. Leave the resistance box connected.

b) Reduce the oscillator output to 20mV p-p and also connect it to the SIGNAL input of the 401A.

Reset:

SENSITIVITY	10mV
2f/f	f

Press the ZERO CHECK button and adjust the OFFSET control to give a

reading of zero on the meter. Release the ZERO CHECK button and adjust the oscillator to give full scale on the 401A meter.

Reset:	SENSITIVITY	100µV
	2f/f	2f

Adjust the resistance box in place of R23 until the meter reads approximately zero.

c) Reset: SENSITIVITY 10mV

Increase the oscillator output to 2.8V p-p and adjust the resistance box in place of R38 until the meter reads approximately zero.

d) Recheck b)

e) Remove the SIGNAL and REFERENCE inputs.

Set:	LINE	off
	BATT	off

Remove the 4003 power pack and replace it with a tested 4007 power pack and oscillator with a frequency of 1kHz. Connect the REF OUTPUT of the 4007 to the SIGNAL input of the 401A.

Set: LINE on

Check zero and then check that the meter reads less than ± full scale.

Set: LINE off

Solder in the required values of R23 and R38 on board J. Note that parallel resistors may be required to obtain the desired accuracy. Replace the original 4003 power pack.

12. Reference channel adjustments

a) Set:	REF OUTER	isolate
	OFFSET	approx. central
	TIME CONSTANT	100ms
	ZERO CHECK	normal
	LF FILTER	off
	PHASE	$0^{\circ}, 0^{\circ}, 0^{\circ}$
	SENSITIVITY	300µV
	LINE REJECT	off
	5kHz HI-CUT	off
	2f/f	f
	LINE	on
	BATT	on
	LF	off
	REF BIAS	off

Apply a 1kHz REFERENCE and a 1Hz SIGNAL to the 401A from the 401A special purpose oscillator. Press the ZERO CHECK and rotate the OFFSET

control so that the meter on the 401A reads 0V ±10mV. Release the ZERO CHECK. Put board F on an extender board. Adjust the potentiometer on board F so that the 1Hz signal as seen on the 401A meter is less than 0.2V p-p.

Reset:

PHASE	$180^\circ, 0^\circ, 0^\circ$

Check that the 1Hz signal is still less than 0.2V p-p, if not, readjust the potentiometer on board F slightly. Finally check the 1Hz signal with PHASE set to $0^\circ, 0^\circ, 0^\circ$. Plug board F into position. Remove the 1Hz signal.

b) Reset:

PHASE	$0^\circ, 0^\circ, 0^\circ$

Using a probe observe the waveform at pin 8 of the edge connector of board H. Check that it is a 1kHz squarewave approximately 1.2V p-p.

Adjust the potentiometer on board H to give a mark-space ratio of 1:1.

c) Apply 2V p-p squarewave at 1kHz to the input of a 422 and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and take the 'ϕ + 90' output of the 422 to the REFERENCE input of the 401A.

Set 422:

trigger	ac, +, auto
offset	0
frequency doubler	off
fixed phase shifts	$0^\circ, 90^\circ$
variable phase shift	90°
phase control	int

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ±100mV.

Reset:

FIXED PHASE	$0^\circ, 90^\circ$

Reset 422:

fixed phase shifts	$0^\circ, 0^\circ$

Adjust the (+90) potentiometer on the 401A motherboard to give 0V±100mV on the 401A meter.

d) Remove the input to the 422 and take the lead to the REFERENCE input of the 401A.

Reset:

FIXED PHASE	$0^\circ, 90^\circ$

Adjust the potentiometer on board G to give 0V ± 100mV on the 401A meter.

e) Reset:

FIXED PHASE	0°
VARIABLE PHASE	90°

Adjust the variable potentiometer on the 401A mother board to give 0V±100mV on the 401A meter.

13 High frequency zero check adjustment

Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	on
PHASE	$0^\circ, 0^\circ, 0^\circ$
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the reference input. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V±10mV. Change the reference frequency to 50kHz and there will be a meter offset. Using S/M radial capacitors across pins 2 and 4 or 2 and 5 of the edge connector of the psd module closest to the front of instrument (copper side) the offset will be reduced to 0V±10mV.

14 $+90^\circ$ checks

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^\circ, 0^\circ, 0^\circ$
SENSITIVITY	100µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 2V p-p sinewave at 50kHz to the input of a 422 and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and take the '$\phi + 90$' output of the 422 to the REFERENCE input of the 401A. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V±10mV. Release the ZERO CHECK.

Set 422:

trigger	ac, +, auto
offset	0
frequency doubler	off
fixed phase shifts	0^{o}, 90^{o}
variable phase shift	90^{o}
phase control	int

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V±100mV.

Reset 401A:

FIXED PHASE	0^{o}, 90^{o}

Reset 422:

FIXED PHASE SHIFTS	0^{o}, 0^{o}

Check that the 401A meter reads 0V±500mV.

b) Reset 401A:

TIME CONSTANT	10s
LF FILTER	on
PHASE	0^{o}, 0^{o}

Reset the oscillator frequency to 5Hz. Take the 'ø' output of the 422 to the REFERENCE input of the 401A:

Reset 422:

FIXED PHASE SHIFTS	0^{o}, 90^{o}
VARIABLE PHASE SHIFT	0^{o}

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V±100mV.

Reset 401A:

FIXED PHASE	0^{o}, 90^{o}

Reset 422:

FIXED PHASE SHIFTS	0^{o}, 0^{o}

Check that the 401A meter reads 0V±500mV.

15 <u>Variable phase checks</u>

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off

PHASE	$0^{o}, 0^{o}, 0^{o}$
SENSITIVITY	100µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 2V p-p squarewave at 50kHz to the input of a 422 and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and take the'ø + 90' output of the 422 to the REFERENCE input of the 401A. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V ± 10mV. Release the ZERO CHECK.

Set 422:

trigger	ac, +, auto
offset	0
frequency doubler	off
fixed phase shifts	$0^{o}, 90^{o}$
variable phase shift	90^{o}
phase control	int

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ± 100mV.

Reset 401A:

VARIABLE PHASE	90^{o}

Reset 422:

fixed phase shifts	$0^{o}, 0^{o}$

Check that the 401A meter reads 0V ± 1V.

b) Reset 401A:

TIME CONSTANT	10s
LF FILTER	on
PHASE	$0^{o}, 0^{o}, 0^{o}$

Reset the oscillator frequency to 5Hz. Take the 'ø' output of the 422 to the REFERENCE input of the 401A.

Reset 422:

fixed phase shifts	$0^{o}, 90^{o}$
variable phase shift	0^{o}

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V±100mV.

Reset 401A:

VARIABLE PHASE	$0^{\circ}, 90^{\circ}$

Reset 422:

fixed phase shifts	$0^{\circ}, 0^{\circ}$

Check that the 401A meter reads 0V±1V.

16. Variable phase linearity check

Set:

REF OUTER	isolate
OFFSET	approx central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^{\circ}, 0^{\circ}, 0^{\circ}$
SENSITIVITY	10mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V rms sinewave at 1kHz to the REFERENCE input of the 401A and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A. Using a high impedance dc voltmeter measure the voltage at the OUTPUT socket of the 401A. Press the ZERO CHECK and adjust the OFFSET control so that the voltmeter reads 0V±2mV. Release the ZERO CHECK.

Reset:

FIXED PHASE	$0^{\circ}, 90^{\circ}$

Check that the voltmeter reads 0V±2mV, if not readjust the VARIABLE PHASE slightly.

Reset:

FIXED PHASE	$0^{\circ}, 0^{\circ}$

Check that the voltmeter reads +1V±5mV.

Reset:

VARIABLE PHASE	45°

Check that the voltmeter reads +0.707V ±20mV.

17. Offset range check

Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	10mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input of the 401A and to an attenuator set to 20dB. Take the output of the attenuator to the SIGNAL input of the 401A. Press the ZERO CHECK and adjust the OFFSET control so that the meter on the 401A reads 0V±10mV. Release the ZERO CHECK. The 401A meter will go off scale. Adjust the OFFSET control so that the 401A meter reads 0V.

Reset:

FIXED PHASE	$0^o, 180^o$

Rotate the OFFSET control in the clockwise direction so that the 401A meter reads 0V.

18. Noise checks

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	1s
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	1μV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Short circuit the SIGNAL input of the 401A. Apply a 1kHz squarewave 1V p-p to the REFERENCE input. Observe the output of the 401A on an oscilloscope set to 2 sec/cm timebase. Check that the noise is not greater than 13mV p-p.

b) Reset the reference frequency to 10Hz and repeat part a). Check that the noise is not greater than 50mV p-p.

19. Signal monitor check

a) Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	1mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the SIGNAL input of the 401A. Observe the waveform at the SIGNAL MONITOR socket on the power pack. Check that it is a 1kHz sinewave approximately 0.8V p-p.

b) Increase the SIGNAL input until the waveform at the SIGNAL MONITOR socket increases to 1V p-p. Insert a 1kΩ resistor in parallel with the socket and check that the waveform falls to 0.5V p-p ± 10%.

c) Remove the 1kΩ resistor and the lead from the SIGNAL MONITOR socket to the oscilloscope. Set the Regulac at its lowest voltage and connect its output to the SIGNAL MONITOR socket: live to inner, earth to outer, neutral unconnected. Increase the Regulac setting to 10V rms and leave for 10 seconds or so. Remove and replace the lead to the oscilloscope. Check that a 1V p-p sinewave at 1kHz is present.

20. Out of phase rejection check

Set:

REF OUTER	isolate
OFFSET	approx. central
TIME CONSTANT	30s
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^o, 0^o, 0^o$
SENSITIVITY	300µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply a 1kHz REFERENCE and a 7kHz SIGNAL from the 401A special purpose oscillator. Set the oscillator 'signal' switch to 'off'. Measure the voltage at the OUTPUT socket using a high impedance dc voltmeter. Press the ZERO CHECK and adjust the OFFSET control so that the voltmeter reads 0V±2mV. Release the ZERO CHECK.

Note the actual reading of the dc voltmeter. Reset the 'signal' switch to 'on' and check that the reading of the voltmeter does not change by more than ±10mV.

21 Time constant checks

Set:

REF OUTER	isolate
OFFSET	approx central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^{\circ}, 0^{\circ}, 0^{\circ}$
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply a 1kHz REFERENCE and a 7kHz SIGNAL from the 401A special purpose oscillator (SIGNAL switch ON). Observe the OUTPUT of the 401A on an oscilloscope. Check that the output waveform is a 100Hz sinewave 100mV p-p±10% with 1kHz sections of 7kHz sinewave superimposed on it. Using the following TIME CONSTANT and SENSITIVITY position check that the 100Hz output has the following amplitudes.

SENSITIVITY	TIME CONSTANT	OUTPUT amplitude p-p±10%
30mV	30ms	100mV
10mV	100ms	"
3mV	300ms	"
1mV	1s	"
300µV	3s	"
1mV	10s	10mV
300µV	30s	"
"	100s	3mV

22 Meter clamp check

Set:

REF OUTER	isolate
OFFSET	approx central
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off

PHASE	$0^\circ, 0^\circ, 0^\circ$
SENSITIVITY	10mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V rms sinewave at 1kHz to the REFERENCE input of the 401A and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A. Press the ZERO CHECK and adjust the OFFSET so that the meter on the 401A reads 0V±10mV. Release the ZERO CHECK. Check that the 401A meter reads +1V±10mV. Remove the REFERENCE and check that the 401A meter clamps at approximately 0V in about 1 second. Replace the REFERENCE and check that the meter returns to +1V in about 10 seconds.

Reset:

LINE	off
BATT	off

Leave the instrument for approximately 1 minute.

Reset:

BATT	on

Check that the meter is clamped at approximately 0V for about 15 seconds before returning to +1V.

appendix II

FINAL TEST PROCEDURE

401A LOCK-IN AMPLIFIER

The following test equipment is required for this test.
Note that "nearest preferred value" refers to E24 series.

TEST EQUIPMENT

500V insulation tester

EXAMPLE EVERSHED AND VIGNOLES MEGGER

High impedance digital dc voltmeter

resolution 1mV
accuracy 0.1%
maximum reading > 1.000V

EXAMPLE IE TYPE DSV 4

Oscilloscope

bandwidth dc to 1MHz
sensitivity 5mV/cm - 5V/cm

EXAMPLE TEKTRONIX 544 + 1A1 PLUG-IN

Signal generator

frequency range 1Hz - 100kHz
output 1mV - 1V rms
sine and square wave

EXAMPLE BROOKDEAL TYPE 471

Attenuator

attenuation 0-100dB

EXAMPLE MARCONI TF1073A

ac Voltmeter

frequency range 10Hz-100kHz
sensitivity 1mV-1V

EXAMPLE HEWLETT-PACKARD 400E

Variable mains transformer 0V - 260V

EXAMPLE REGULAC RB 2-M

Phase shifter

frequency range 5Hz - 50kHz
phase shift 0-90°
accuracy 1°

EXAMPLE BROOKDEAL TYPE 422

401A special purpose oscillator

ORDER OF THE BOARDS

Order of the plug-in boards from the back to the front of the 401A is given below:

J	reference input amplifier and trigger.
H	MSG I.
G	MSG II.
F	MSG with twin output driver.
	phase sensitive detector module.
C	30/-40dB amplifier.
B	filter amplifier.

The signal preamplifier, board A, is mounted on the front panel behind the SIGNAL socket.

TEST PROCEDURE

1 Line plug impedance checks

Plug a tested 4003 rechargeable ac power pack into the back of the 401A. Measure the following line plug impedances.

a) earth to frame <0.5Ω
b) earth to line >100MΩ
c) earth to neutral >100MΩ
d) live to neutral >100MΩ with LINE switch off

} use megger

e) live to neutral about 300Ω on 230V range
f) live to neutral about 75Ω on 115V range

} with LINE switch on

g) SIGNAL BNC outer to frame <0.5Ω
h) SIGNAL MONITOR, REFERENCE, OUTPUT BNC outers to frame >100MΩ.

2 Reference input checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off } these switches are to be found
REF BIAS	off } on the mother board (K) inside the 401A.

Apply a 1V p-p sinewave at 1kHz to the REFERENCE input of the 401A. Check that the UNTRIGGERED lamp is off. Reduce the oscillator output to zero and check that the UNTRIGGERED lamp is now on.

b) Repeat a) at 1Hz.

c) Repeat a) at 50kHz.

d) Apply a 1V p-p sinewave at 1kHz to the REFERENCE input of the 401A. Observe the waveform at pin 8 of the edge connector of board H with an oscilloscope. Check that it is a 1kHz squarewave approximately 1.2V p-p. Reduce the oscillator output to 20mV p-p and also connect it to the SIGNAL input of the 401A.

Reset:

SENSITIVITY	10mV

Press the ZERO CHECK button and adjust the OFFSET control to give a reading of zero on the meter. Release the ZERO CHECK button and adjust the oscillator output to give full scale on the 401A meter.

Reset:

SENSITIVITY	100μV
2f/f	2f

Check that the meter reads less than full scale.

Reset:

SENSITIVITY	10mV
2f/f	2f

Increase the oscillator output to 2.8V p-p and check that the meter reads less than full scale.

Replace the 4003 power pack with a tested 4007 power pack and oscillator set to 1kHz. Connect the REF OUTPUT of the 4007 to the SIGNAL input of the 401A. Check zero and then check that the meter reads less than ± full scale.

3. Signal channel checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^{o}, 0^{o}, 0^{o}
SENSITIVITY	30µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
REF BIAS	off
LF	off

Apply approximately 1V p-p sinewave at 1kHz to the SIGNAL input of the 401A via an attenuator. Using a x1 oscilloscope probe connect the output of board B (pin B) to the input of the ac voltmeter set to -10dB (0.3V) range. Set the attenuator to 30dB and adjust the oscillator output to get 0dB on the voltmeter.

Reset:

SENSITIVITY	100µV

Reset the attenuator to 0dB and check that the voltmeter reads 0dB ± 0.1dB.

b) Reset the oscillator frequency to 5kHz and check that the voltmeter reads 0dB ± 0.1dB.

Reset:

5kHz HI-CUT	on

Check that the voltmeter reads -3dB ± $\frac{1}{2}$dB.

Reset:

5kHz HI-CUT	off

c) Reset the oscillator frequency to 50kHz and check that the voltmeter reads -3dB ± $\frac{1}{2}$dB.

d) Reset the oscillator to 50Hz and check that the voltmeter reads 0dB ± 0.1dB.

Reset:

LINE REJECT	on

Check that the voltmeter reads less than -30dB.

Reset:

LINE REJECT	off

e) Transfer the oscilloscope probe from the ac voltmeter to the oscilloscope. Reset the oscillator frequency to 5kHz. Adjust the oscillator output to give 1V p-p on the oscilloscope. Reset the oscillator frequency to 5Hz and check that the output of board B as seen on the oscilloscope is not less than 0.7V p-p.

f) Reset the oscillator to 1Hz. Check that the output of board B is now less than 0.7V p-p.

Reset:

LF	on

Check that the output of board B is now not less than 0.7V p-p.

g) Reset the oscillator frequency to 1kHz. Using an oscilloscope probe connect the output of board C (pin B) to the input of the ac voltmeter set to the -50dB (3mV) range.

Reset:

SENSITIVITY	100mV

Adjust the oscillator output so that the voltmeter reads 0dB. Using the following attenuator, SENSITIVITY, and voltmeter range settings check that the voltmeter reads 0dB ± 0.1dB:

attenuator dB	SENSITIVITY	range dB (mV)
10	30mV	-50 (3)
20	10mV	"
30	3mV	"
40	1mV	"
50	300µV	"
60	100µV	"
60	30µV	-40 (10)
60	10µV	-30 (30)
60	3µV	-20 (100)
60	1µV	-10 (300)

h) Press the ZERO CHECK and check that the reading on the ac voltmeter falls to zero.

Remove the SIGNAL input and the scope probe.

4 psd reference breakthrough and LF FILTER checks

a) Apply 1V p-p sinewave at 100Hz to the REFERENCE input.

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Observe the waveform at the OUTPUT socket using an oscilloscope triggered from the REFERENCE input. Check that it is an integrated squarewave of reference frequency less than 50mV p-p.

b) Reset:

LF FILTER	on

Check that the reference breakthrough is no longer present, ie the output is pure dc.

5 Meter checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	on
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	off
BATT	off
LF	off
REF BIAS	off

Check the mechanical zero on the meter.

b) Reset:

LINE	on
BATT	on

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control until the dc voltmeter reads +1V ± 2mV. Check that the meter on the 401A reads +1V, within the thickness of the needle.

Rotate the OFFSET control until the dc voltmeter reads -1V ±2mV. Check that the meter on the 401A reads -1V ±10mV.

6 Output impedance check

Set:

REF OUTER	isolate
OFFSET	immaterial

TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	on
PHASE	0°, 0°, 0°
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control until the dc voltmeter reads +1V ±10mV. Connect a 1kΩ resistor in parallel with the OUTPUT socket and check that the dc voltage falls to 500mV ±10%. Remove the 1kΩ resistor.

7 Output protection check

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	on
PHASE	0°, 0°, 0°
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control until the dc voltmeter reads +1V ±10mV. Remove the lead from the OUTPUT socket to the dc voltmeter. Set the Regulac at its lowest voltage and connect its output to the OUTPUT socket: live to inner, earth to outer, neutral unconnected.

Increase the Regulac setting to 20V rms and leave for 10 seconds or so. Remove and replace the lead to the voltmeter. Check that the voltmeter reads +1V ±10mV.

8 Overload indicator checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Measure the dc voltage at the OUTPUT socket using a high impedance dc voltmeter. Rotate the OFFSET control in the anticlockwise direction until the OVERLOAD indicator comes on. (At this point the output voltage should be approximately -1.2V). Now rotate it in the clockwise direction and note the voltage reading on the dc voltmeter when the indicator goes off. Check that the indicator goes off at -1.1V ±20mV.

Rotate the OFFSET control in the clockwise direction until the OVERLOAD indicator comes on. (At this point the output voltage should be approximately +1.2V). Now rotate it in the anticlockwise direction and note the voltage reading on the dc voltmeter when the indicator goes off. Check that the indicator goes off at +1.1V ±20mV.

Remove the REFERENCE input and the lead from the OUTPUT.

b) Apply 1V p-p sinewave at 1kHz to the SIGNAL input. Increase the input level until the OVERLOAD indicator comes on. Check that at this point the input is between 2.5V and 2.7V p-p. Remove the input.

c) Reset:

SENSITIVITY	10µV

Apply 10mV p-p sinewave at 1kHz to the SIGNAL input. Increase the input level until the indicator comes on. Check that at this point the input is 35mV p-p ±2mV.

9 High frequency zero check

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	on
PHASE	0^o, 0^o, 0^o
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the REFERENCE input. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V ±10mV. Change the reference frequency to 50kHz and check that the 401A meter reads 0V ±10mV.

10 Reference channel checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^o, 0^o, 0^o
SENSITIVITY	300μV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply a 1kHz REFERENCE and a 1Hz SIGNAL to the 401A from the 401A special purpose oscillator. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V ±10mV. Release the ZERO CHECK.

Check that the 1Hz signal as seen on the 401A meter is less than 0.2V p-p.

Reset:

PHASE	180^o, 0^o, 0^o

Check that the 1Hz signal is still less than 0.2V p-p.

b) Apply 2V p-p squarewave at 1kHz to the input of a 422 and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and take the 'ϕ+90' output of the 422 to the REFERENCE input of the 401A.

Set 422:

trigger	ac, +, auto
offset	0
frequency doubler	off
fixed phase shifts	0^o, 90^o
variable phase shift	90^o
phase control	int

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ±100mV.

Reset 401A:

FIXED PHASE	0^o, 90^o

Reset 422:

fixed phase shift	0^o, 0^o

Check that the 401A meter reads 0V ±100mV.

c) Remove the input to the 422 and take the lead to the REFERENCE input of the 401A.

Reset:

FIXED PHASE	0^o, 90^o

Check that the 401A meter reads 0V ±100mV.

11 $+90^{o}$ checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^{o}, 0^{o}, 0^{o}
SENSITIVITY	100μV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 2V p-p squarewave at 50kHz to the input of a 422 and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and take the 'ϕ+90' output of the 422 to the REFERENCE input of the 401A. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V ±10mV. Release the ZERO CHECK.

Set 422:

trigger	ac, +, auto
offset	0
frequency doubler	off
fixed phase shifts	0^{o}, 90^{o}
variable phase shift	90^{o}
phase control	int

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ±100mV.

Reset 401A:

FIXED PHASE	0^{o}, 90^{o}

Reset 422:

fixed phase shifts	0^{o}, 0^{o}

Check that the 401A meter reads 0V ±1V.

b) Reset 401A:

TIME CONSTANT	10s
LF FILTER	on
PHASE	0°, 0°

Reset the oscillator frequency to 5Hz. Take the 'ø' output of the 422 to the REFERENCE input of the 401A.

Reset 422:

fixed phase shifts	0°, 90°
variable phase shift	0°

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ±100mV.

Reset 401A:

FIXED PHASE	0°, 90°

Reset 422:

fixed phase shifts	0°, 0°

Check that the 401A meter reads 0V ±1V.

12 Variable phase checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0°, 0°, 0°
SENSITIVITY	100µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 2V p-p squarewave at 50kHz to the input of a 422 and to an

attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and take the 'ϕ·+90' output of the 422 to the REFERENCE input of the 401A. Press the ZERO CHECK and rotate the OFFSET control so that the meter on the 401A reads 0V ±10mV. Release the ZERO CHECK.

Set 422:

trigger	ac, +, auto
offset	0
frequency doubler	off
fixed phase shifts	0^o, 90^o
variable phase shift	90^o
phase control	int

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ±100mV.

Reset 401A:

VARIABLE PHASE	90^o

Reset 422:

fixed phase shifts	0^o, 0^o

Check that the 401A meter reads 0V ±1V.

b) Reset 401A:

TIME CONSTANT	10s
LF FILTER	on
PHASE	0^o, 0^o, 0^o

Reset the oscillator frequency to 5Hz. Take the 'ϕ' output of the 422 to the REFERENCE input of the 401A.

Reset 422:

fixed phase shifts	0^o, 90^o
variable phase shift	0^o

Adjust the variable phase shift on the 422 so that the meter on the 401A reads 0V ±100mV.

Reset 401A:

VARIABLE PHASE	0^o, 90^o

Reset 422:

fixed phase shifts	0^o, 0^o

Check that the 401A meter reads 0V ±1V.

13 Gain check

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
FIXED PHASE	0^o, 0^o
VARIABLE PHASE	90^o
SENSITIVITY	10mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V rms sinewave at 1kHz to the REFERENCE input of the 401A and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A and to the ac voltmeter set to the 10mV range. Using a high impedance dc voltmeter measure the voltage at the 'dc output' socket of the voltmeter. Adjust the oscillator amplitude so that the dc voltmeter reads 1V ±2mV. Remove the dc voltmeter from the ac voltmeter and use it to measure the voltage at the OUTPUT socket of the 401A. Press the ZERO CHECK and adjust the OFFSET control so that the dc voltmeter reads 0V ±2mV. Release the ZERO CHECK. Check that the dc voltmeter reads 0V ±2mV, if not readjust the VARIABLE PHASE slightly.

Reset:

FIXED PHASE	0^o, 90^o

Check that the dc voltmeter reads -1V ±2mV.

Reset:

FIXED PHASE	0^o, 180^o

Check that the dc voltmeter reads ±1V ±5mV.

14 Offset range check

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^{o}, 0^{o}, 0^{o}
SENSITIVITY	10mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p squarewave at 1kHz to the REFERENCE input of the 401A and to an attenuator set to 20dB. Take the output of the attenuator to the SIGNAL input of the 401A. Press the ZERO CHECK and adjust the OFFSET control so that the meter on the 401A reads 0V ±10mV. Release the ZERO CHECK.

The 401A meter will go off scale. Adjust the OFFSET control so that the 401A meter reads 0V.

Reset:

FIXED PHASE	0^{o}, 180^{o}

Rotate the OFFSET control in the clockwise direction so that the 401A meter reads 0V.

15 Noise checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	1s
ZERO CHECK	normal
LF FILTER	off
PHASE	0^{o}, 0^{o}, 0^{o}
SENSITIVITY	1µV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Short circuit the SIGNAL input of the 401A. Apply a 1kHz squarewave 1V p-p to the REFERENCE input. Observe the output of the 401A on an oscilloscope set to 2s/cm timebase. Check that the noise is not greater than 13mV p-p.

b) Reset the reference frequency to 10Hz and repeat part a). Check that the noise is not greater than 50mV p-p.

16. SIGNAL MONITOR checks

a) Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	$0^\circ, 0^\circ, 0^\circ$
SENSITIVITY	1mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V p-p sinewave at 1kHz to the SIGNAL input of the 401A. Observe the waveform at the SIGNAL MONITOR socket on the power pack. Check that it is a 1kHz sinewave approximately 0.8V.

b) Increase the SIGNAL input until the waveform at the SIGNAL MONITOR socket increases to 1V p-p. Insert a 1kΩ resistor in parallel with the socket and check that the waveform falls to 0.5V p-p ± 10%.

c) Remove the 1kΩ resistor and the lead from the SIGNAL MONITOR socket to the oscilloscope. Set the Regulac at its lowest voltage and connect its output to the SIGNAL MONITOR socket: live to inner, earth to outer, neutral unconnected. Increase the Regulac setting to 10V rms and leave for 10 seconds or so. Remove and replace the lead to the oscilloscope. Check that a 1V p-p sinewave at 1kHz is present.

17. Out-of-phase rejection check

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	30s
ZERO CHECK	normal
LF FILTER	off

PHASE	0^o, 0^o, 0^o
SENSITIVITY	300μV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply a 1kHz REFERENCE and a 7kHz SIGNAL from the 401A special purpose oscillator. Set the oscillator 'signal' switch to 'off'. Measure the voltage at the OUTPUT socket using a high impedance dc voltmeter. Press the ZERO CHECK and adjust the OFFSET control so that the voltmeter reads 0V ±2mV. Release the ZERO CHECK.

Note the actual reading of the dc voltmeter. Reset the 'signal' switch to 'on' and check that the reading of the voltmeter does not change by more than ±10mV.

18 Meter clamp check

Set:

REF OUTER	isolate
OFFSET	immaterial
TIME CONSTANT	100ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^o, 0^o, 0^o
SENSITIVITY	10mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply 1V rms sinewave at 1kHz to the REFERENCE input of the 401A and to an attenuator set to 40dB. Take the output of the attenuator to the SIGNAL input of the 401A. Press the ZERO CHECK and adjust the OFFSET so that the meter on the 401A reads 0V ±10mV. Release the ZERO CHECK. Check that the 401A meter reads +1V ±10mV. Remove the REFERENCE and check that the 401A meter clamps at approximately 0V in about 1 second. Replace the REFERENCE and check that the meter returns to +1V in about 10 seconds.

Reset:

LINE	off
BATT	off

Leave the instrument for approximately 1 minute.

Reset:

BATT	on

Check that the meter is clamped at approximately 0V for about 15 seconds before returning to +1V.

19 Time constant checks

Set:

REF OUTER	isolate
OFFSET	approximately central
TIME CONSTANT	10ms
ZERO CHECK	normal
LF FILTER	off
PHASE	0^{o}, 0^{o}, 0^{o}
SENSITIVITY	100mV
LINE REJECT	off
5kHz HI-CUT	off
2f/f	f
LINE	on
BATT	on
LF	off
REF BIAS	off

Apply a 1kHz REFERENCE and a 7kHz SIGNAL from the 401A special purpose oscillator (SIGNAL switch ON). Observe the OUTPUT of the 401A on an oscilloscope. Check that the output waveform is a 100Hz sinewave 100mV p-p ±10% with the 1kHz sections of 7kHz sinewave superimposed on it. Using the following TIME CONSTANT and SENSITIVITY positions, check that the 100Hz output has the following amplitudes:

SENSITIVITY	TIME CONSTANT	OUTPUT amplitude p-p ±10%
30mV	30ms	100mV
10mV	100ms	"
3mV	300ms	"
1mV	1s	"

300µV	3s	"
1mV	10s	10mV
300µV	30s	"
300µV	100s	3mV

Remove the special purpose oscillator.

20 Final phase check

Set:

SENSITIVITY	10mV
TIME CONSTANT	10ms

Connect a 1V p-p sinewave at 1kHz to the SIGNAL and REFERENCE inputs of the 401A. Press the ZERO CHECK button and adjust the offset control until the meter reads zero. Release the ZERO CHECK button and

Set:

FIXED PHASE +90°

Check that the meter reads zero ±5mV (1/2 scale).

Set:

FIXED PHASE	0°
VARIABLE PHASE	+90°

Check that the meter reads zero ±5mV. Finally,

Reset:

VARIABLE PHASE 0°

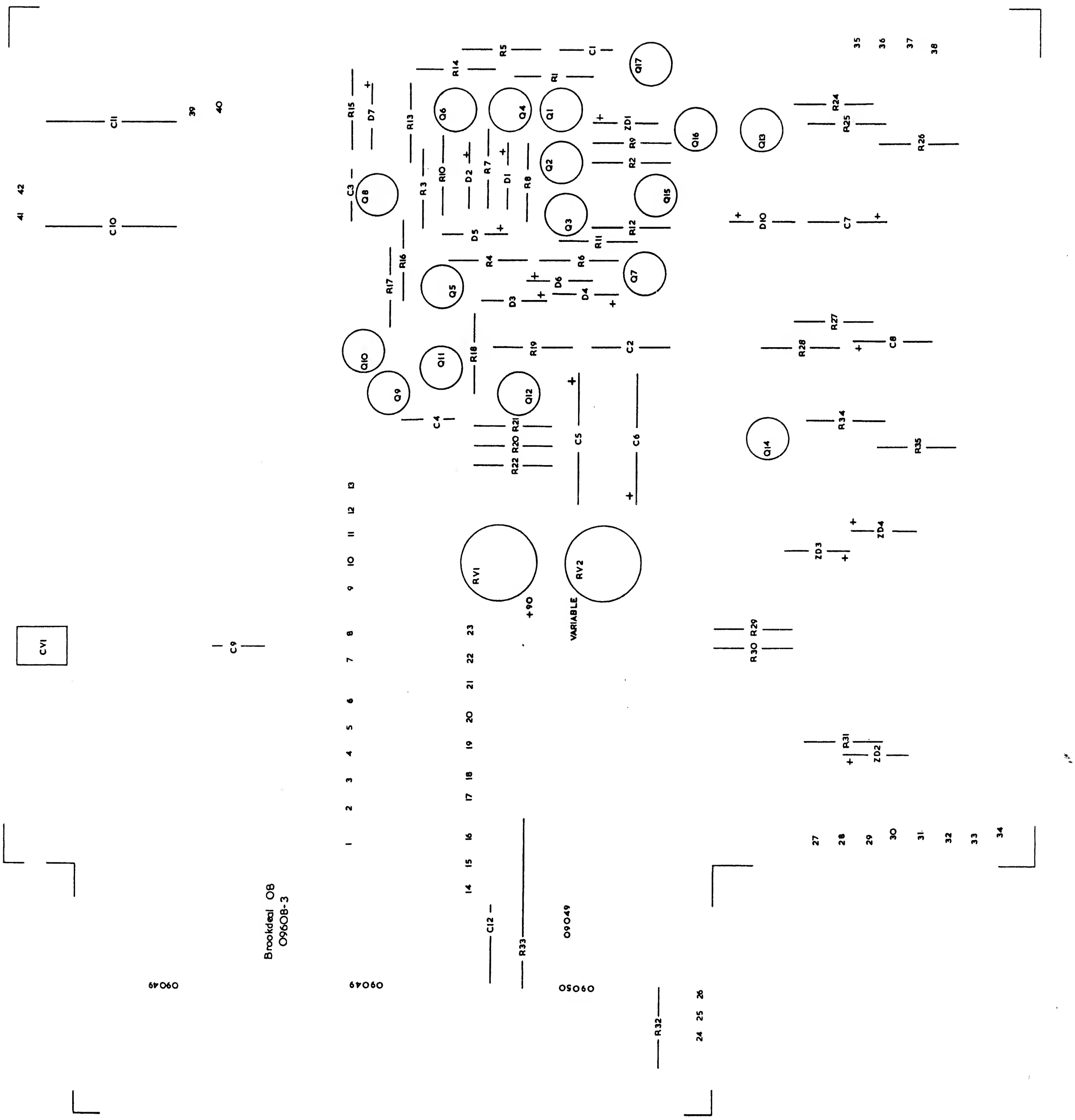


fig 33(b) motherboard (K) - component layout

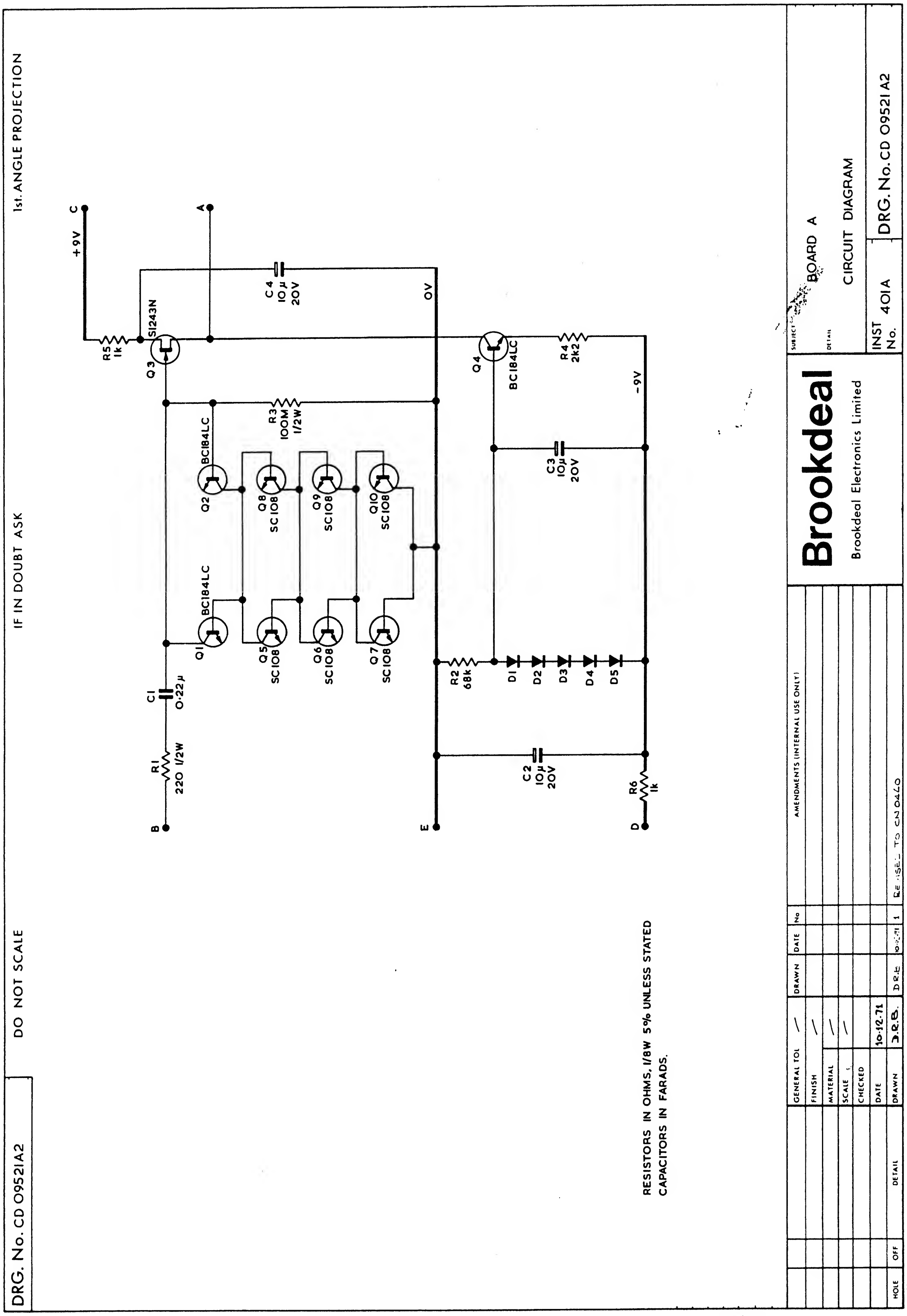


fig 34 (a) board A - circuit diagram

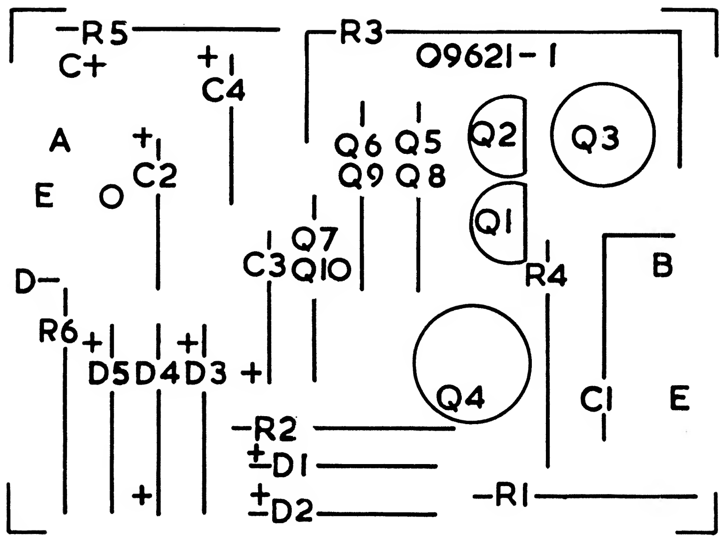


fig 34 (b) board A - component layout

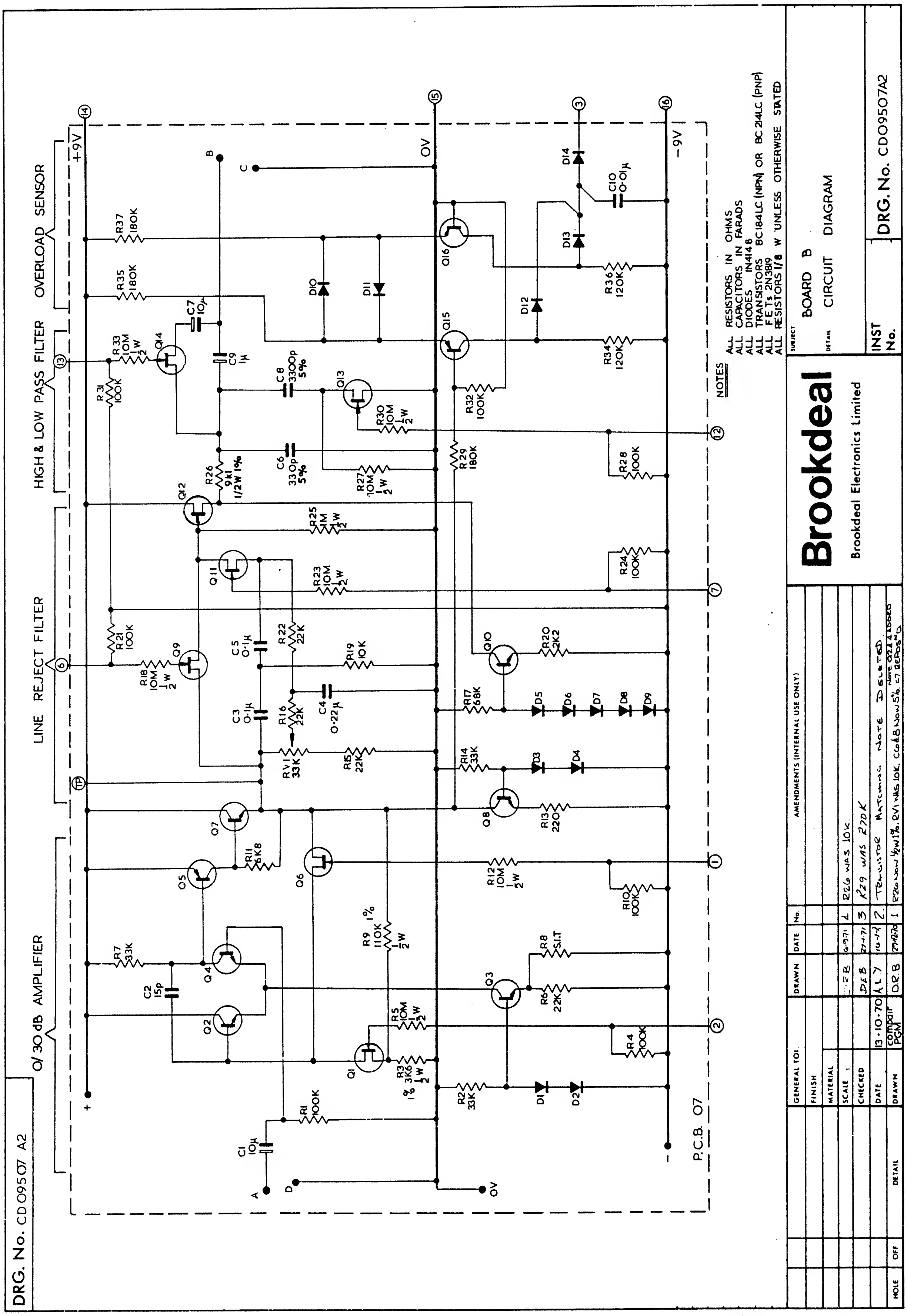


fig 35 (a) board B - circuit diagram

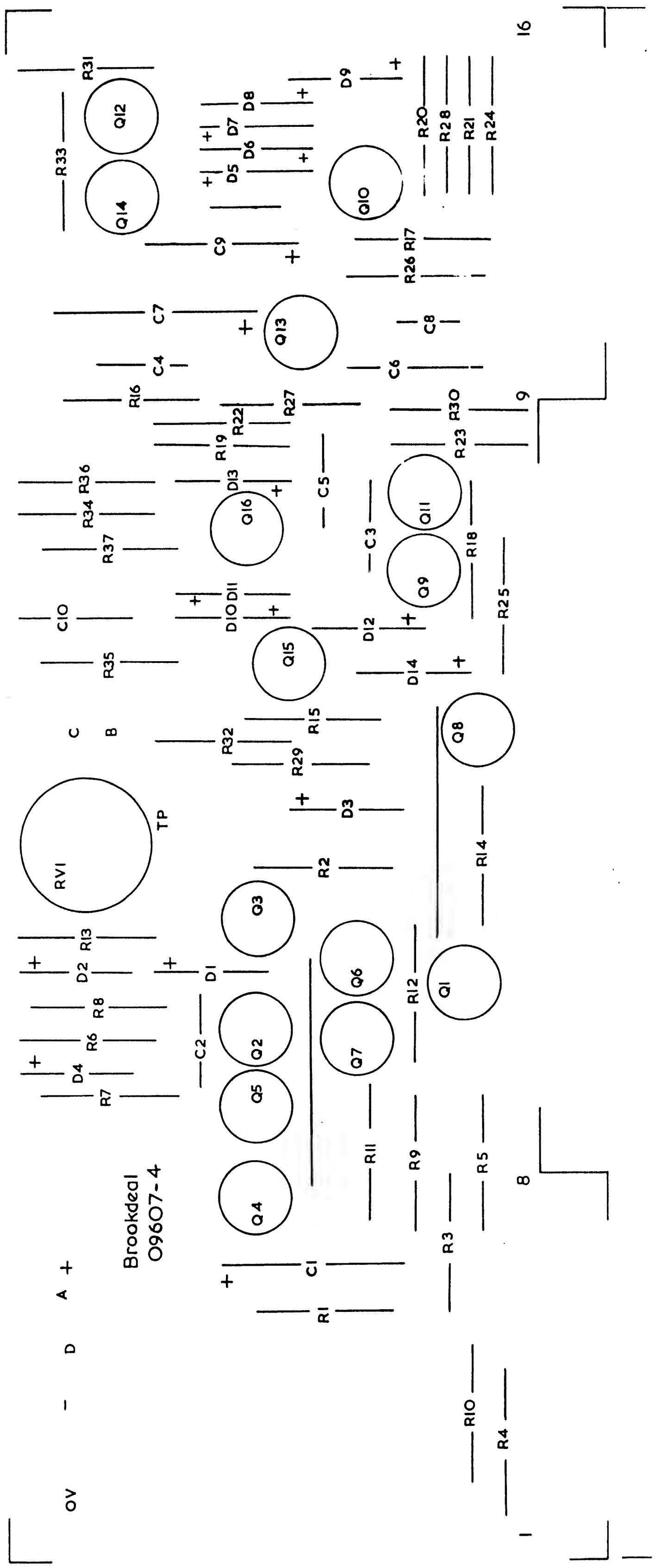


fig 35(b) board B - component layout

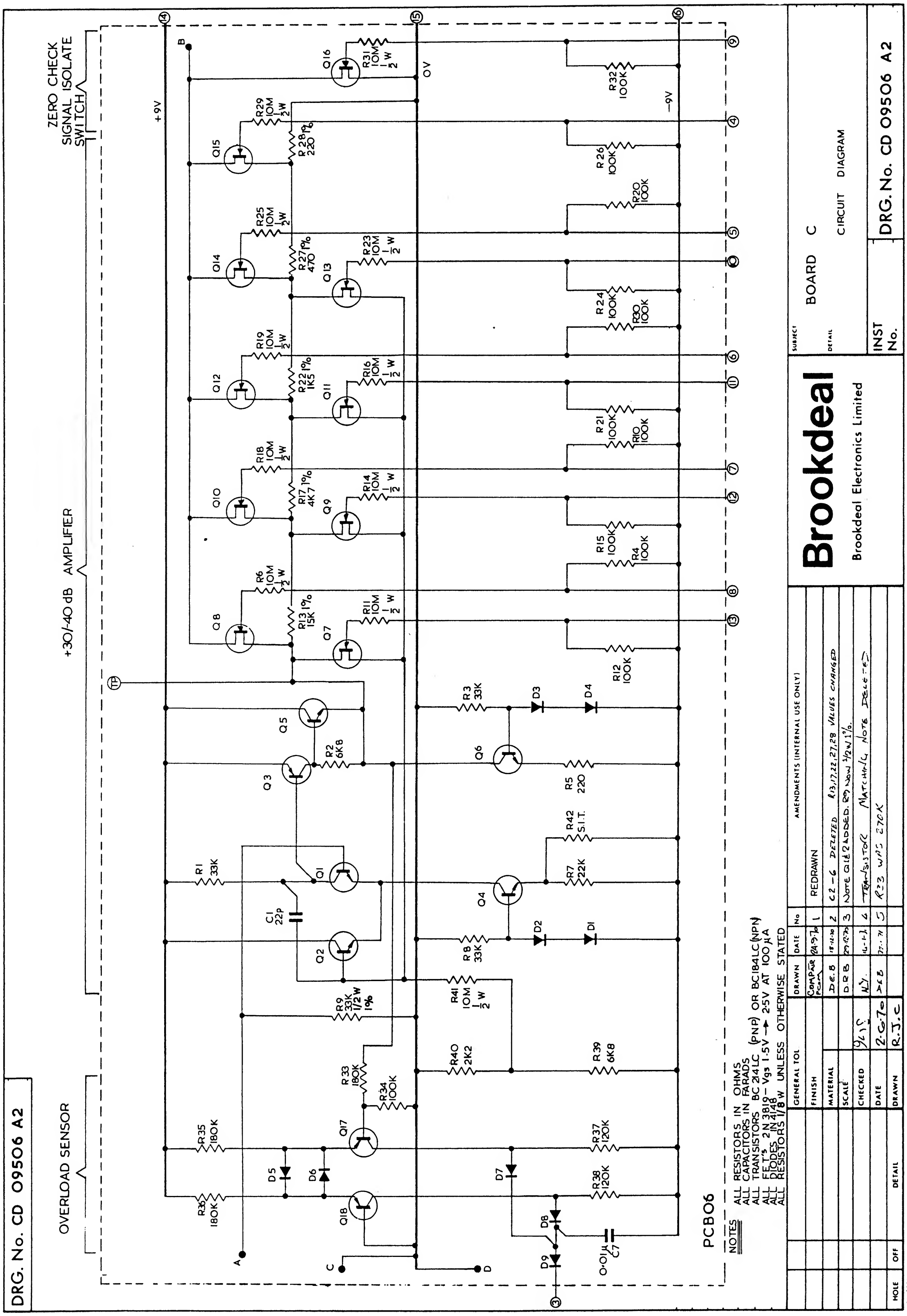


fig 36 (a) board C - circuit diagram

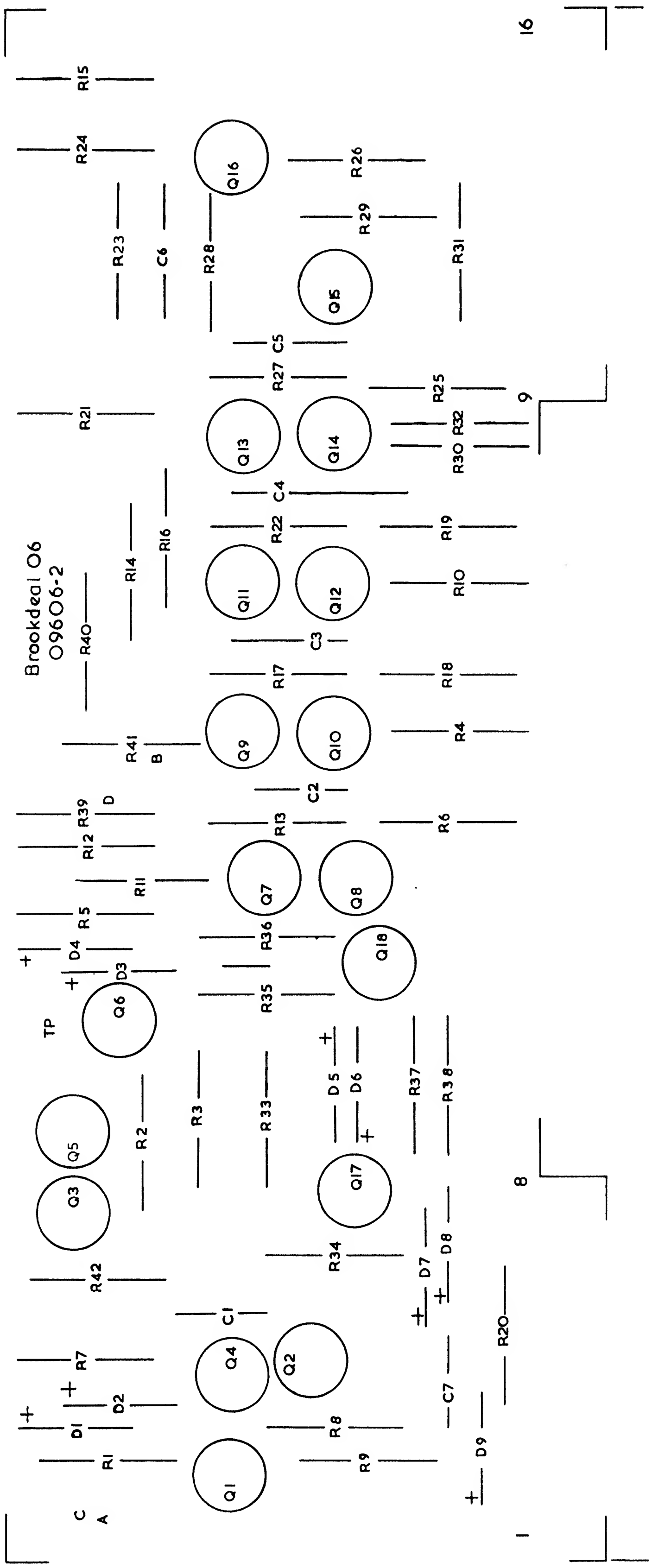


fig 36(b) board C - component layout

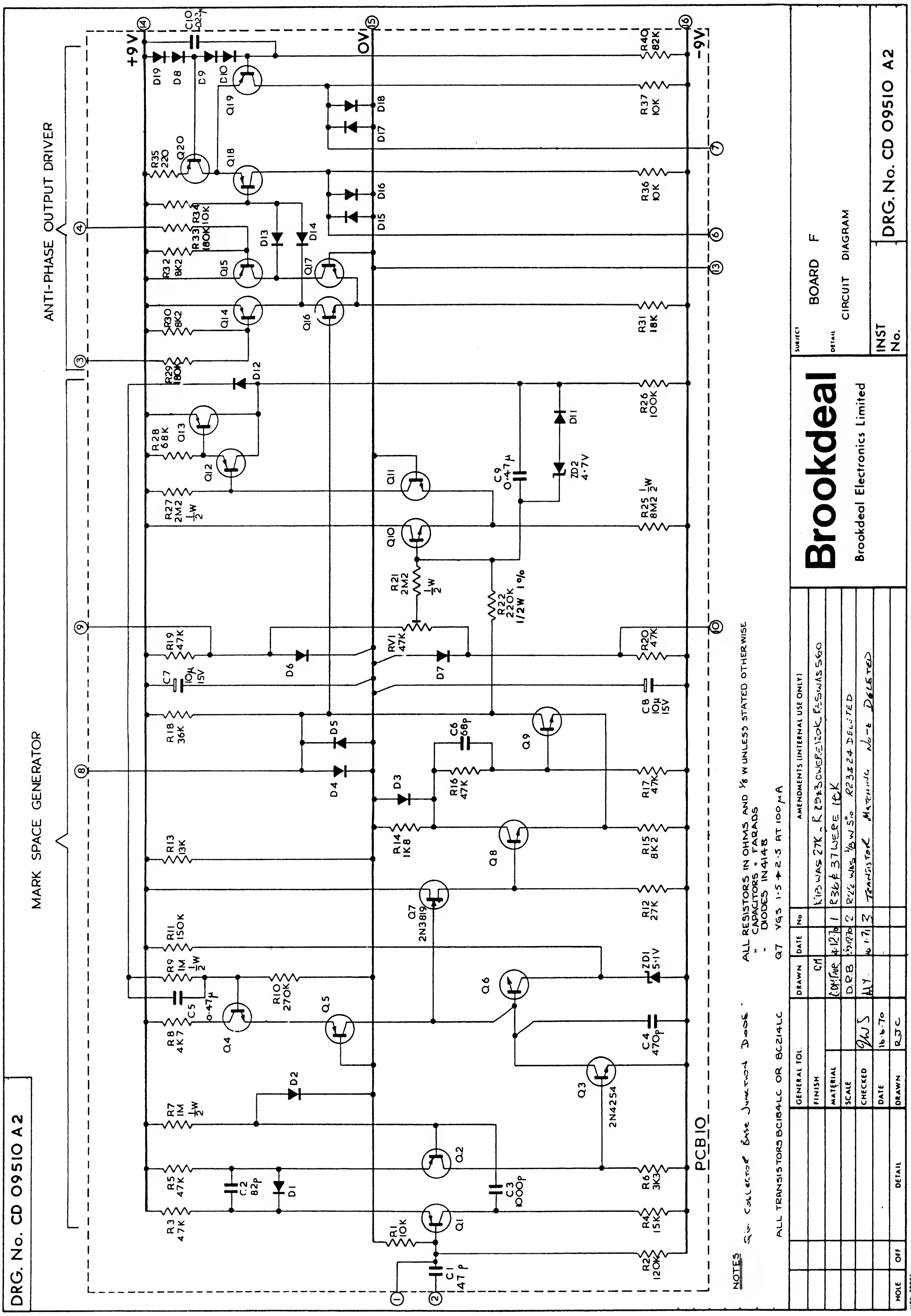


fig 37 (a) board F - circuit diagram

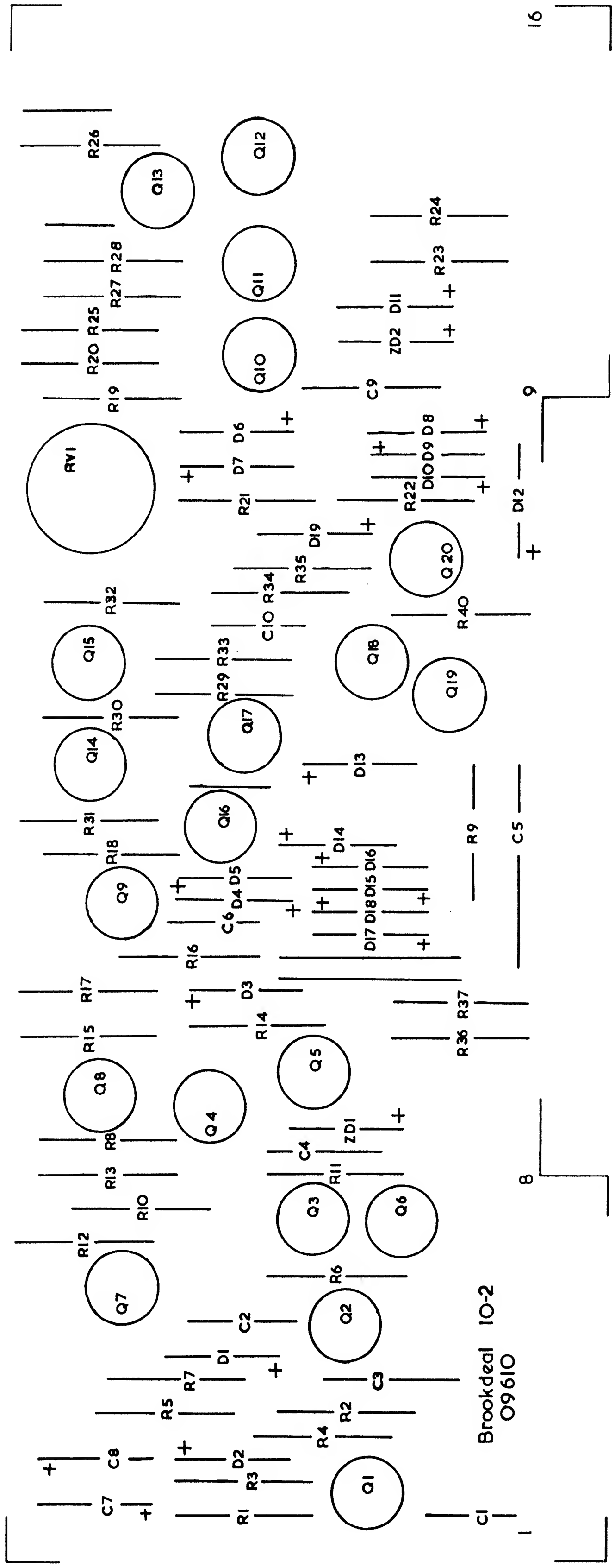


fig 37 (b) board F - component layout

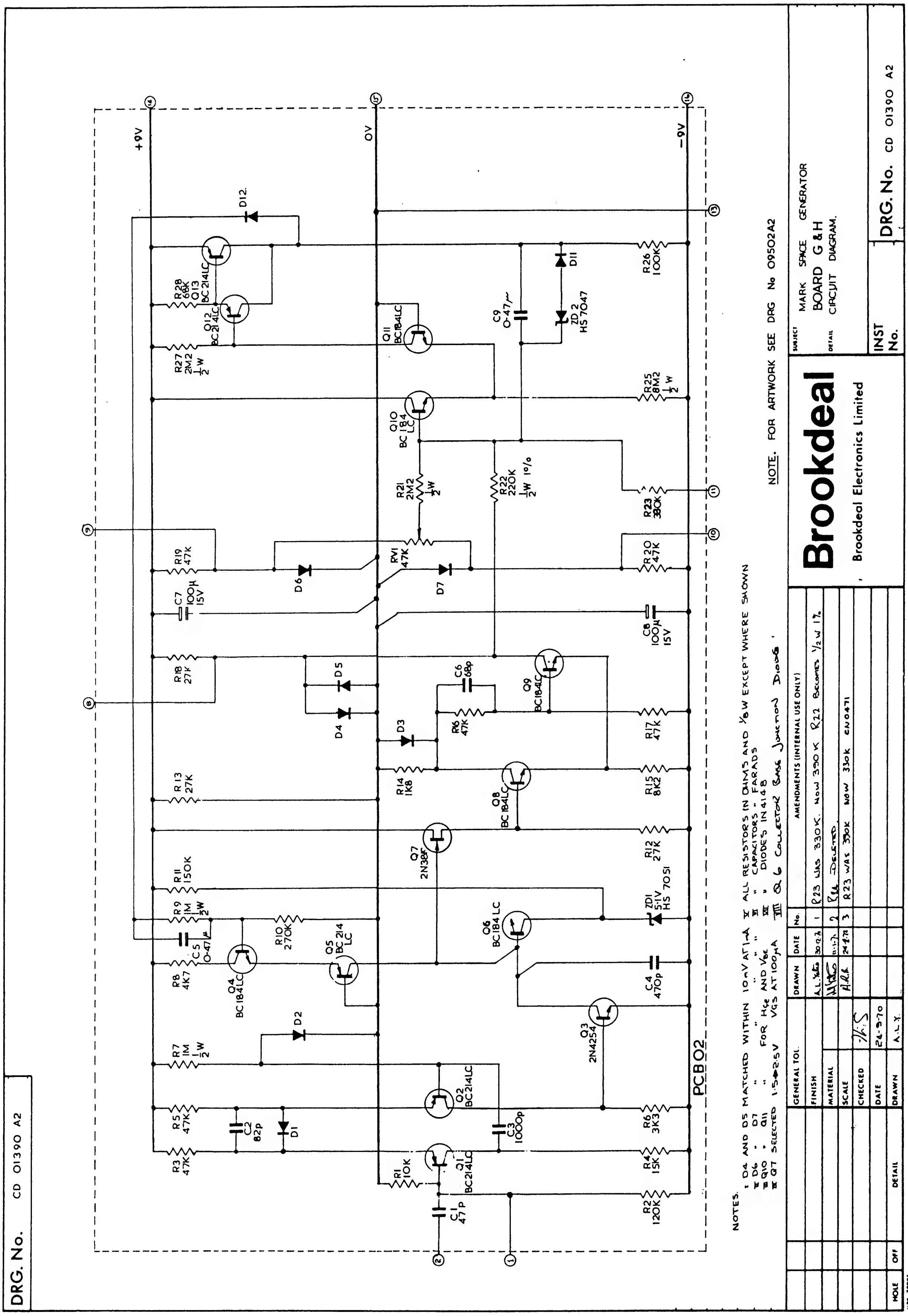


fig 38 (a) boards G and H - circuit diagram

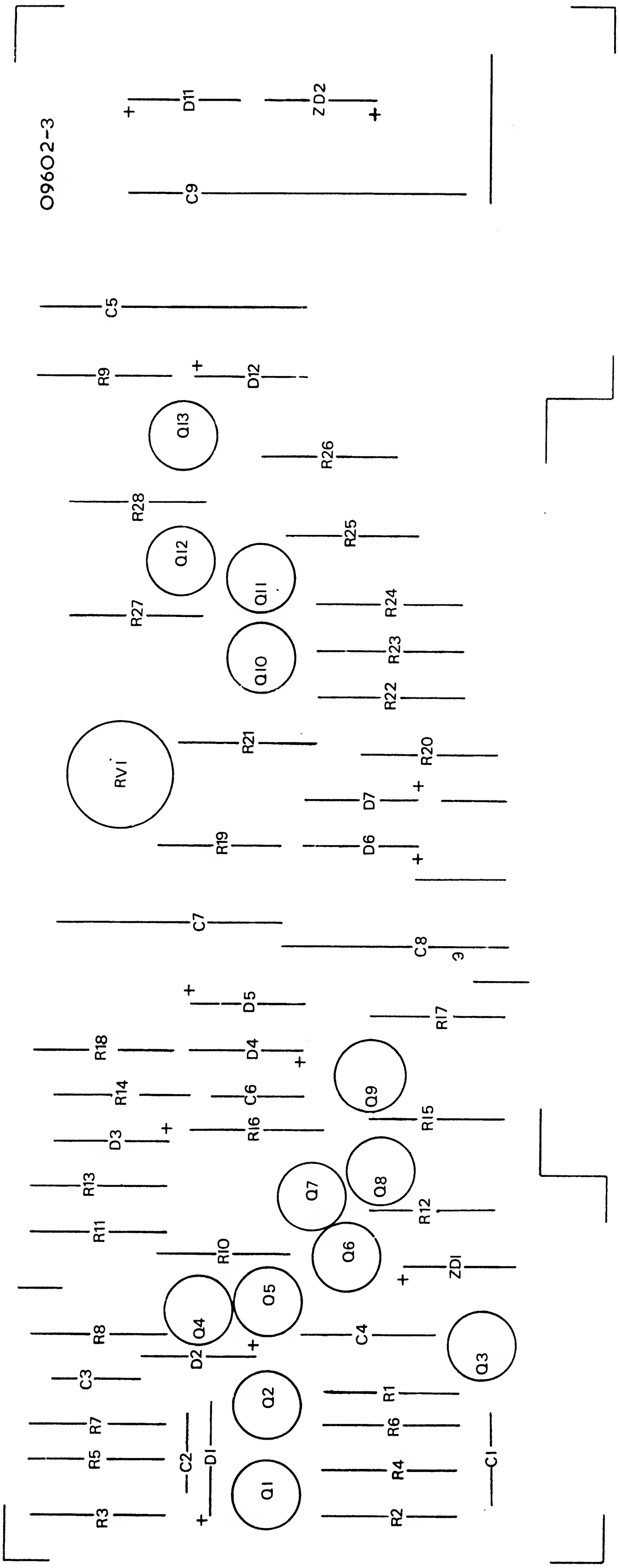


fig 38 (b) boards G and H - component layout

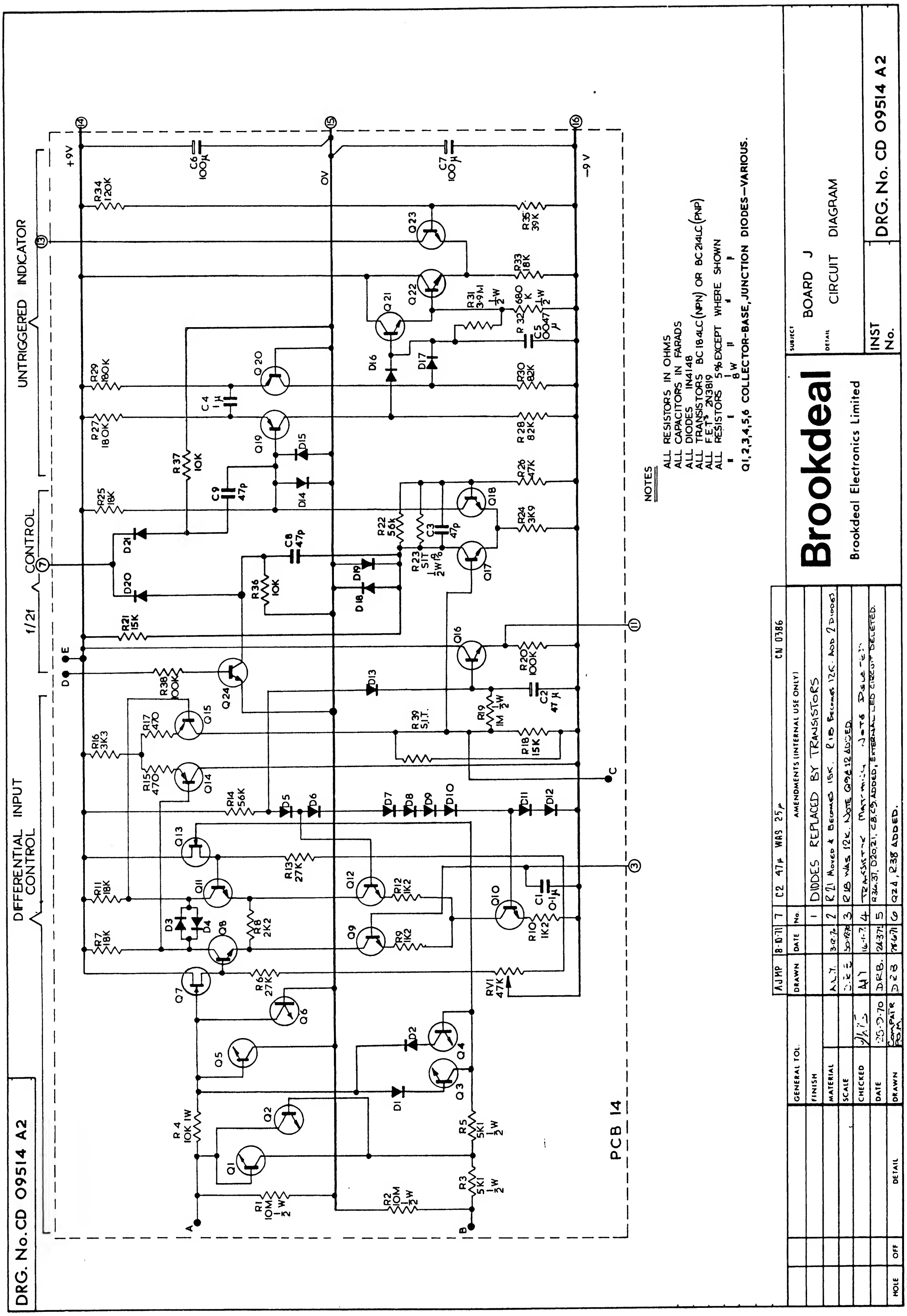


fig 39 (a) board J - circuit diagram

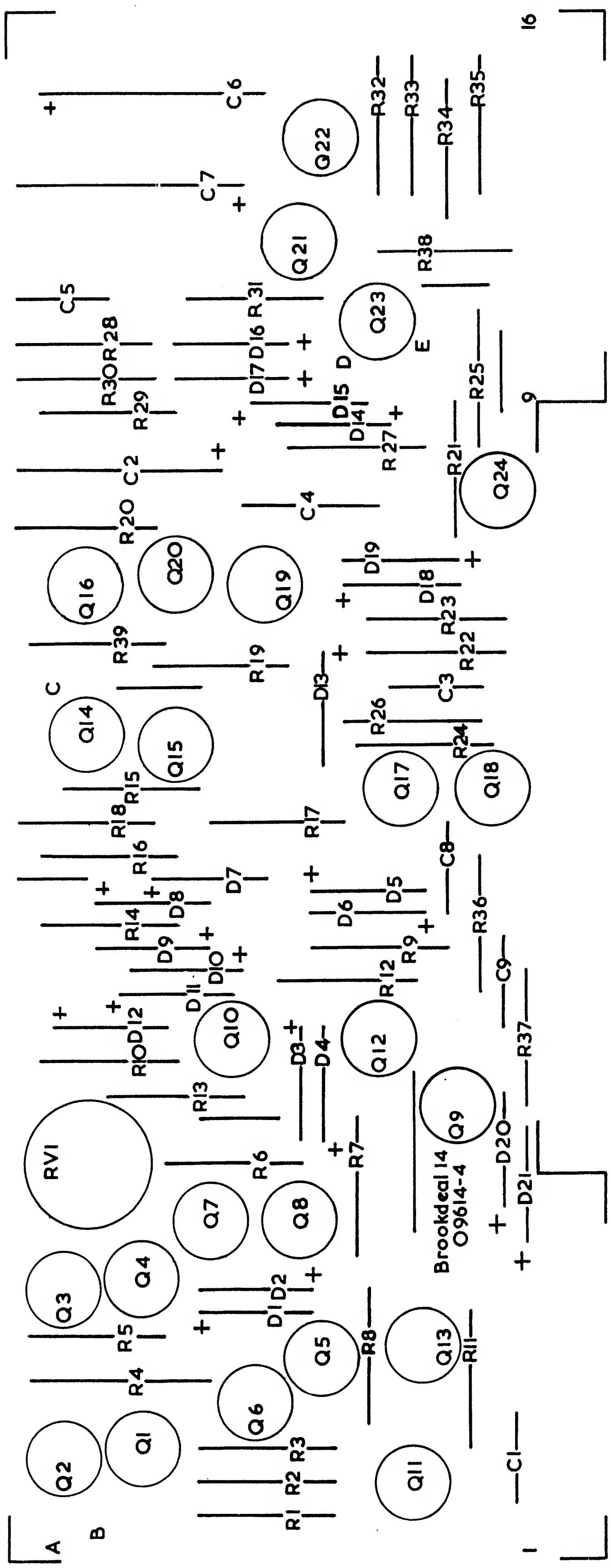


fig 39 (b) board J - component layout

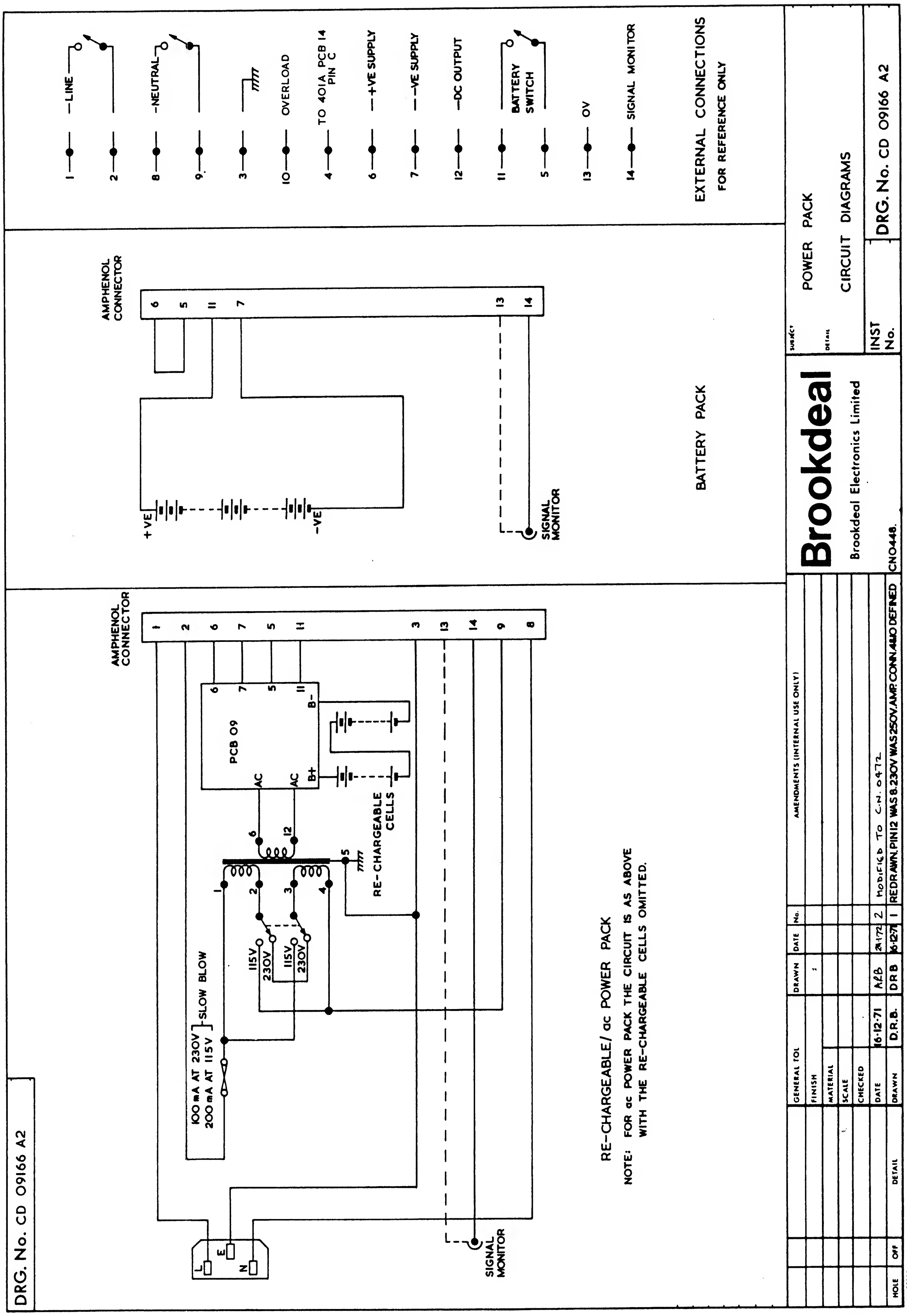


fig 40 (a) power pack circuit diagrams (4001, 4002, 4003)

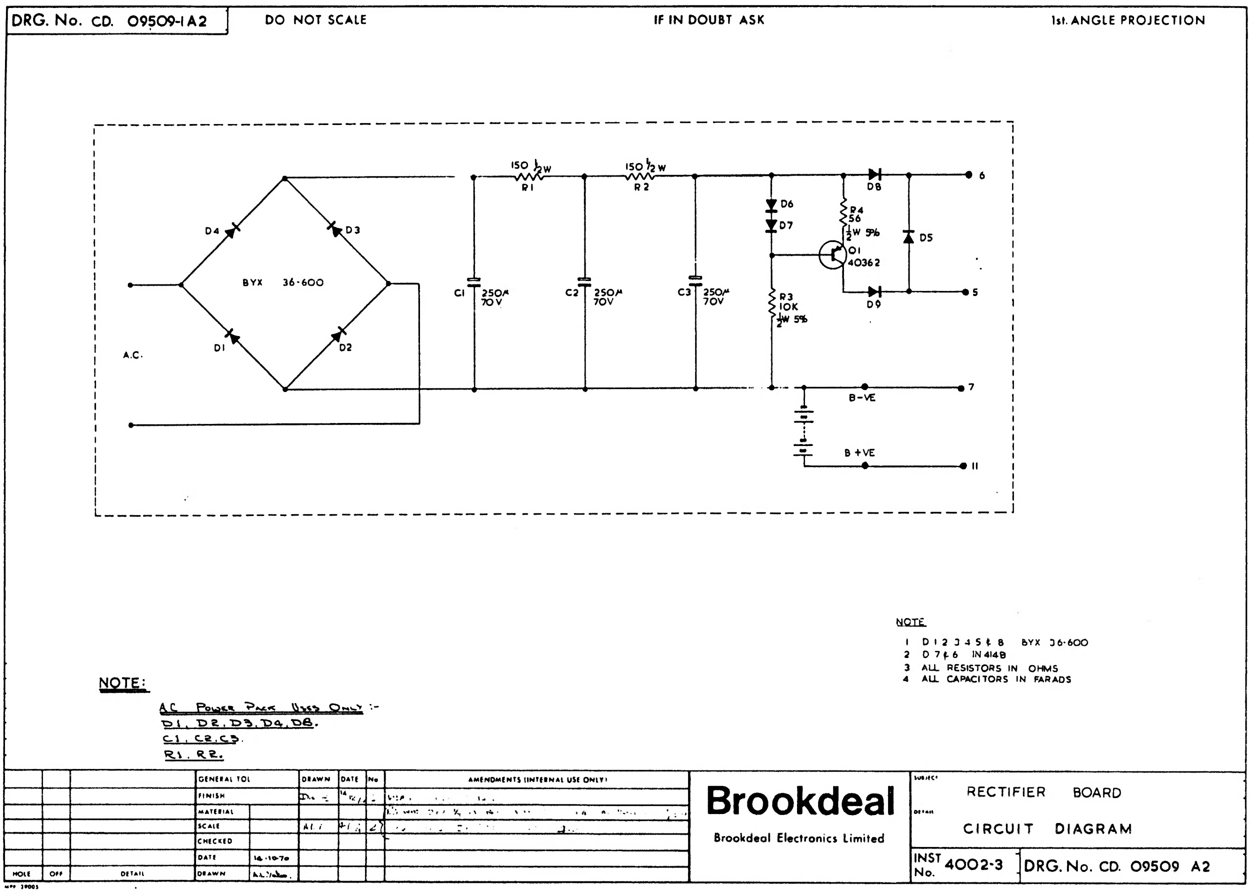


fig 40 (b) rectifier board circuit diagram (4002, 4003)

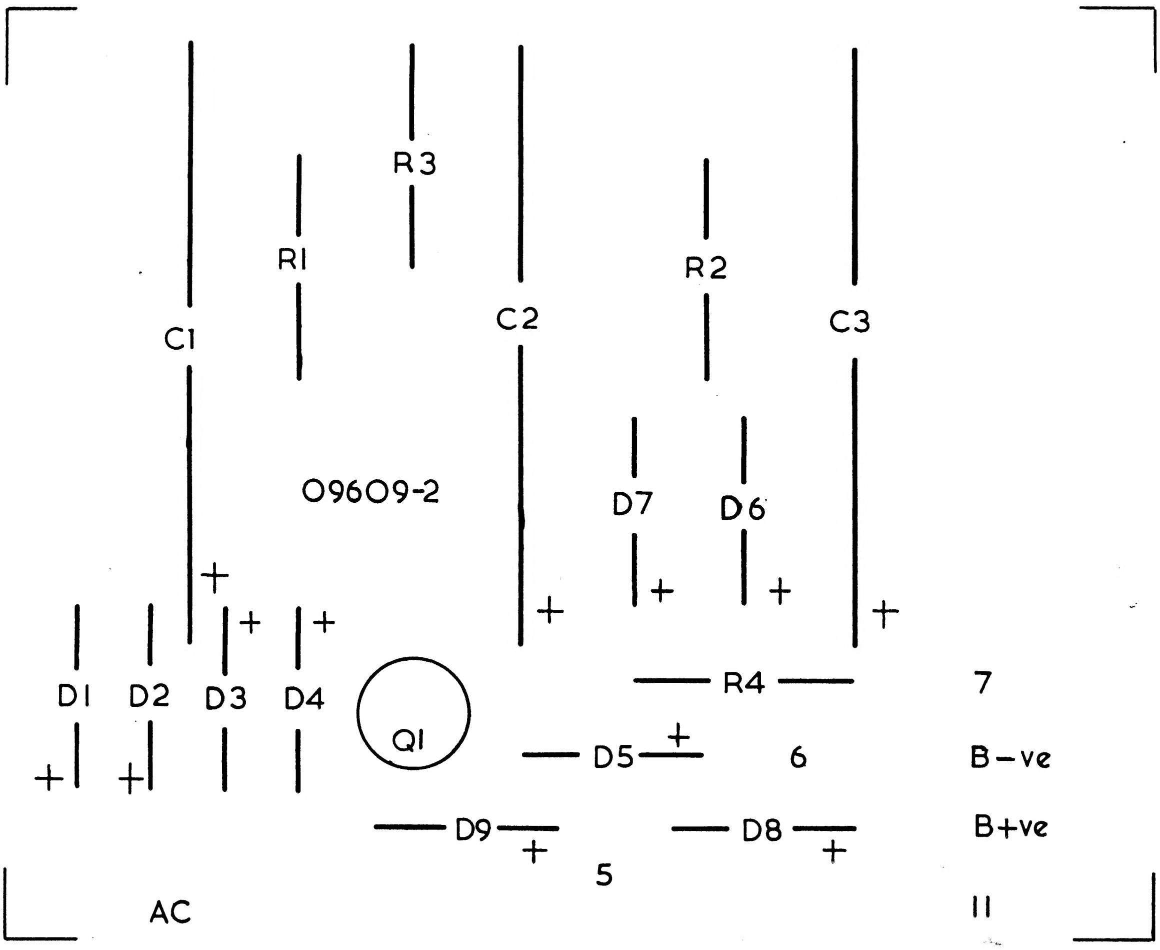


fig 40 (c) rectifier board component layout

Publication No. M401A0
February 1972

Printed in
Great Britain

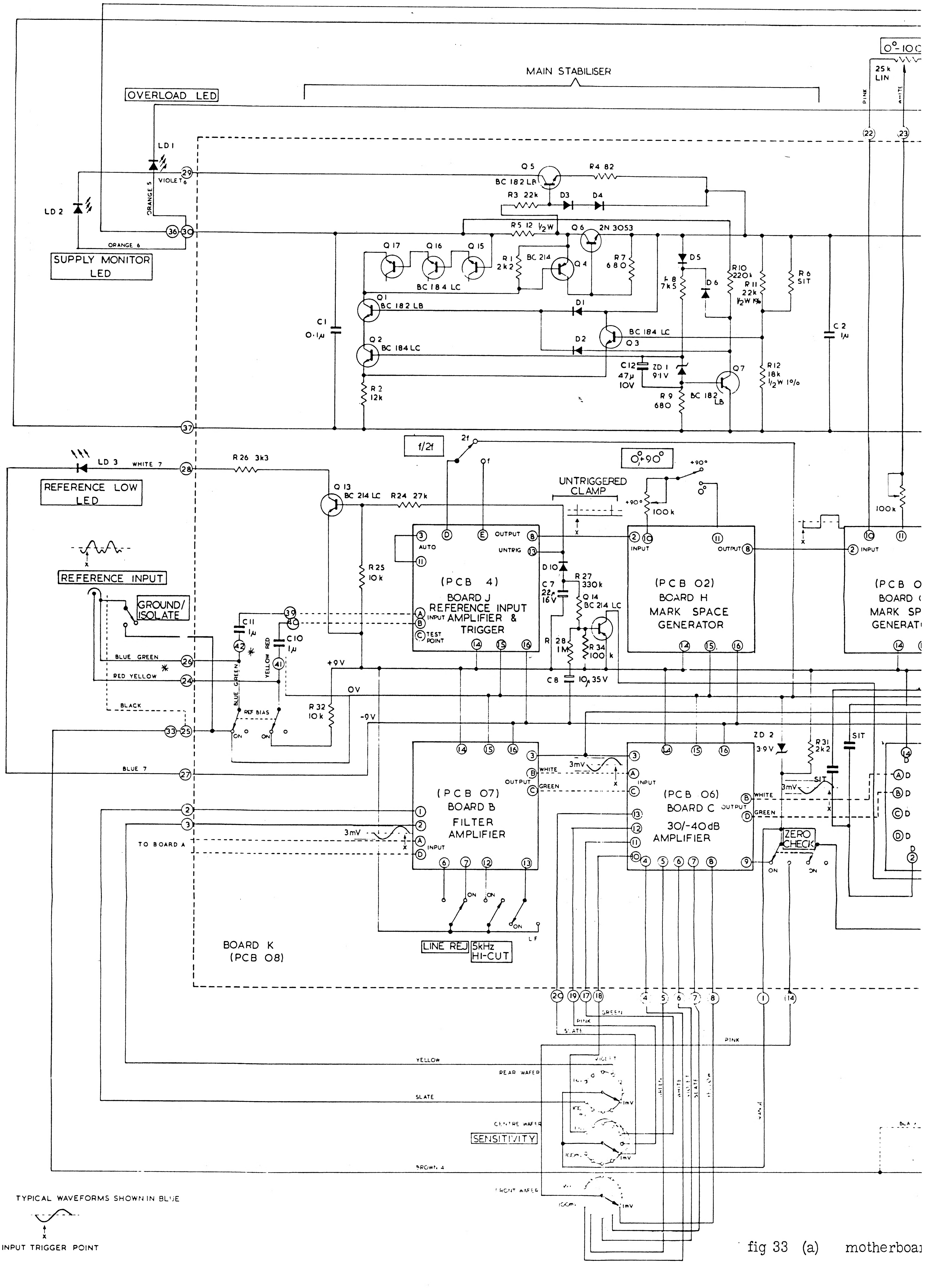
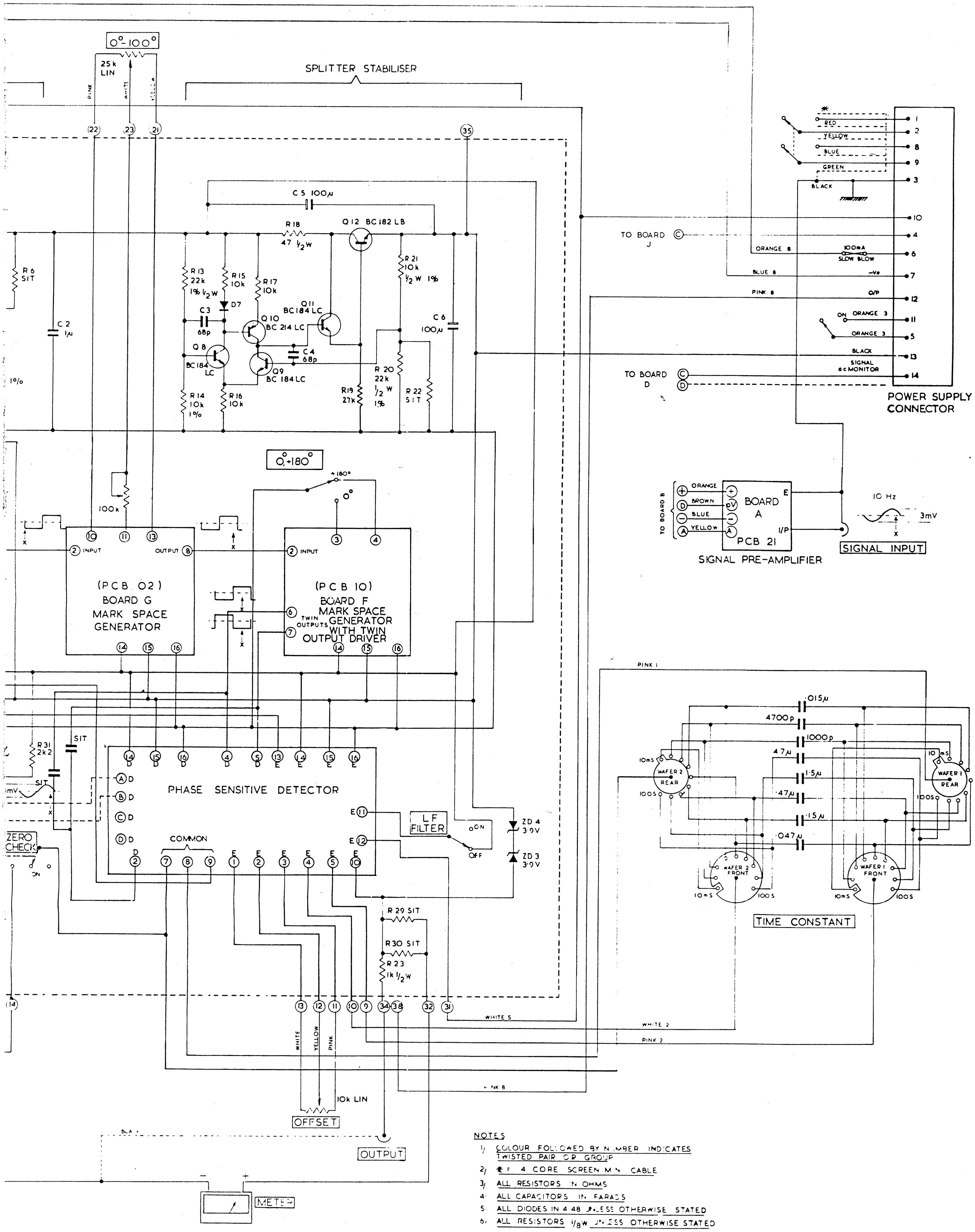


fig 33 (a) motherboar



3 (a) motherboard (K) - general and switching arrangement